NUCLEAR ENGINEERING VOL. 5 NO. 51 AUGUST, 1960

Retrenchment

WHEN it became clear in 1959 that, in spite of very much increased unit capacity, the Government was intending to pursue the nuclear power programme on the basis of the megawatts stipulated in the 1957 White Paper rather than the implied number of stations, we took pains to point out that it was the total capacity that was specified and the number of stations estimated only in the light of experience then available. Whilst the increased unit size created a problem for the contracting consortia it was unfair to lay the blame on anything but the natural evolution of the industry.

The best that can be said of the new extension to 1968 is that, in part, it is a rationalization of a programme already well behind schedule and it might have been worse. There is still no disguising the fact, however, that this is a deliberate repudiation of a definite undertaking. Having persuaded industry to make large investments in nuclear energy the Government has announced that it has changed its mind and industry must make the best of it.

Well, so it will. The cut is not wholly unexpected and the integration of the groups will soften the effects. There are, none the less, certain aspects of the revision that require examination. The superficial explanation is that it will save the country £90 million of capital expenditure at a time when credit restrictions are necessary; but has not the continuous lobbying of the coal industry been largely instrumental in precipitating the decision? Neglecting the fact that the accumulating coal stocks are not the result of nuclear building, has it not been felt necessary to provide a positive proof of Government support in order to boost morale?

It is outside the scope of this journal to discuss the economic brinksmanship that appears to dictate our finances, but is not the quotation of £90 million a gross simplification of the economic result? Quite apart from the higher running costs of conventional stations, what recognition is given to the effect this will have on the cost of future nuclear stations? Is it assumed that development costs scheduled to be written off against a greater number of kilowatts installed will remain the same? Is there no penalty in fuel costs because of the need to pay charges on the uranium still being stockpiled and higher charges on the first fuel elements because the production lines are not fully employed? What happens to the AEA's royalties on power stations? How is this to be recalculated now?

Even if we ignore these facets there are still aspects of the decision which are disturbing. Is it in fact a cabinet decision, a Board ruling or is the AEA itself behind it? It is well known that established sections of the Generating Board felt that the 1957 programme had been wished upon them and the sceptics were concerned that they would be forced to carry the responsibility for decisions taken by others. But, indications are that the White Paper emanated from Charles II Street and there are strong grounds for believing that the original rumours concerning the cut some months ago came from the Authority's ranks.

It is also intriguing to speculate on when the decision was actually made. How was it that Hirsch (President of Euratom) was able to state so confidently to the American Nuclear Society in February that the British programme was being put back by two years? Yet why was this so strenuously denied by the Generating Board and why was some mention not made at the World Power Conference in Madrid? It is known that great care was put into the preparation of the Generating Board's article; much time and effort was spent in the analysis of the figures and in the projection of the probable cost of future stations both conventional and nuclear. Are we to take it that these projections are still applicable or already out of date? We have in the past protested against the habit of using conferences overseas for making announcements of essentially domestic interest, but it seems equally wrong that papers should be delivered to important gatherings with the deliberate intention of misleading.

Is there a purely commercial reason behind the timing and would it have been very different if the Sizewell and Dungeness tenders had not been at a critical state? By arranging for these tenders to be submitted within a few weeks of each other the CEGB were able to carry out very shrewd bargaining with the contracting groups and they have been able to use the Sizewell tender to bring the price of Dungeness down to the absolute minimum. Would any of the tenders have been quite so low if it had been known that the programme was to be cut immediately after?

Just what are we to believe when next a nuclear programme is announced and industry is given to understand that a certain reactor system is to be exploited, for example, the AGR? How is it to plan its development programme if political expediencies are to take precedence over what must be long-term organization? It would be comforting to believe that we have now seen the last of these programme manipulations and that we can look forward to a stable rate of expansion but it is difficult at this time to believe that this will be the case. Let us hope that the Government in future, even if it shows little concern for the nuclear industry, will at least pay some heed to its prestige abroad because the steady eating of words that has gone on over the past two years is not doing us any good at all.

The Enrico Fermi Case

NOT only in Europe is nuclear energy development a prey to political manœuvring, although it is politics of a different type that have created the unhappy position in which the Enrico Fermi reactor now stands in the United States. At the time of writing a United States court has ruled that the construction permit issued by the U.S. AEC to PRDC should be withdrawn.

This is not just a local wrangle but a fight that can have the most serious repercussions upon reactor development all over the world. The U.S. AEC is not accepting the decision lying down and the first move would appear to be to call for a re-evaluation by the full number of judges operating in the court circuit concerned. Even so there are strong reasons for believing that whatever the decision, the party losing out will try to take the case to the Supreme Court.

Dissension over the Enrico Fermi reactor has gone on for many years and one must suspect the unions, who oppose the construction of the plant on the basis of safety and financial competence of the owners as having ulterior motives.

Should the present verdict be upheld fast reactor technology would lose a most valuable experimental plant, one that is a necessary adjunct in the Western complex to supplement the findings from EBR-1 and -2 and Dounreay.

The financial loss to the companies concerned would, of course, be heavy and all utilities contemplating the installation of a nuclear station would be chary of taking a similar risk. Again, the choice of site would prove extremely difficult if, as the court demands, the AEC must find compelling reasons for building close to a town (and the term close is highly elastic). Also, if a full technical evaluation were necessary, based upon incontrovertible experimental evidence, before a plant could be started, then it would be almost impossible for advanced reactor systems to get built except on remote AEC sites.

The U.S. AEC would be required to completely reorganize its method of working and almost inevitably years of delay would result. In all matters the competence of the U.S. AEC to make decisions would always be in question and owners of reactors would run the risk of facing an endless succession of lawsuits

While it is apparent that in the United States there is a greater public concern (and ignorance) over environmental safety than in, say, the U.K., those responsible for jeopardizing the prospects of the Enrico Fermi plant would do well to re-assess the ramifications of their actions and the disservice that they will be doing to the whole American power industry, and those whose lives depend upon it.

Joining Euratom

SO, after all this time the U.K. Government has approached Euratom with a view to becoming a full member and to its surprise has found that the doors are no longer wide open as they were two years ago. Then we strongly advocated that the U.K. should throw in its lot with the nuclear activities of the inner six but time has not stood still over the intervening months and conditions have changed a great deal.

One presumes that the recent move was made as a political gesture to the Common Market and had very little relevance to nuclear energy developments as such, otherwise why should the Government so suddenly take this step without proper consultations with the Atomic Energy Authority and contrary to their generally held policy? In the early days the Atomic Energy Authority was against joining Euratom on the basis that they would be forced to give up a great deal of commercially valuable knowledge for little recompense and they were also of the opinion that the Consortia would not appreciate close collaboration on immediately exploitable systems. This attitude has been somewhat modified over the years and the U.K./Euratom agreement has been implemented by an exchange of information on the two main Authority projects, the fast reactor and latterly the AGR. With regard to the civil stations the Authority is quite anxious to increase its collaboration with France, in particular to exchange its experience on the reactor properties of magnesium alloys and the irradiation behaviour of uranium metal and alloys. The Authority is however very conscious of the considerable drain on manpower already caused by participation in international ventures and is anxious not to increase this drain unnecessarily.

At the same time the United Kingdom has been a stalwart supporter of the O.E.E.C. projects and can take no small credit for the success of the European Nuclear Energy Agency which alone amongst the international organizations can be considered to be operating at a minimum expense and maximum efficiency. Quite apart from the two reactor projects, Halden and Dragon, and the Eurochemic processing plant project, ENEA has now almost completed the drafting of international rules for insurance and is currently conducting a survey of ship projects with a view to organizing European collaboration.

The balancing action of Britain between the inner six and the outer seven is responsible in no small measure for the smooth running of ENEA but if Britain were to become a full-time member of Euratom then this balance would no longer exist and there is every likelihood that the Agency would become prematurely overwhelmed by the Euratom organization, large in number but lacking a unified positive policy.

Few will deny the ultimate desirability of integrating European technical effort and two or three years ago joining Euratom would have been a logical way of bringing this about. But it is too late for Britain to join as a founder member, able to exert a significant influence on the structure and the immediate aims of the commission. The process of fusion now is likely to vitiate the efforts of ENEA, absorb an undesirable amount of effort of the Atomic Energy Authority and alienate the sympathies of what would then be the outer six without bringing any attendant advantages in the nuclear energy field.

It may be possible to work out a formula which safeguards existing interests of both industry and governments in the outer seven but this cannot be achieved by a sudden unprepared approach without due heed to the consequences. Having backed ENEA in the past it seems unnecessary to change horses in mid-stream. It should not be impossible to arrange a progressively closer integration between the Agency and the commission, but this would be better preceded by a unification of our overall energy policies.

DIGEST...

Surveying Significant News

TNPG Lands Dungeness Contract

A letter of intent has been sent by the Central Electricity Generating Board to The Nuclear Power Group, covering the contract for the 550 MW nuclear power station at Dungeness. This, the fifth of the Board's stations, will conform to the previous pattern of twin reactors, CO_2 cooled, graphite moderated natural uranium fuelled with Magnox cladding. Capital cost is reported to be less than £98/kW.

Dresden Driven to Full Power

General Electric's boiling water reactor power station at Dresden was run up to full power for the first time on June 30. Criticality was first achieved on October 15 last year since when experiments have been carried out on the plant at various power levels. The original operating licence issued by the U.S. AEC was for half-power operation and at one time it was feared that there would be delays in granting the full-power certificate. There are six months still to go before the official date of handing over and experiments will continue with the plant to determine its behaviour under different conditions.

AEA Issues Sixth Annual Report

The sixth annual report of the United Kingdom Atomic Energy Authority was published on July 14 and covers the period March, 1959 to March, 1960. The report constitutes a brief survey of the Authority's activities and few details are given of any individual aspects. No decision has yet been taken on whether a heavy water moderated reactor should be developed parallel with the AGR but mention is made of studies into a two-zone steam generating heavy water reactor in which light water is heated in one zone, flashed to steam outside the reactor and returned for superheating in the second zone. A decision whether or not to go ahead with this project is expected in September.

Court Sets Aside PRDC's Construction Permit

On June 10 by a majority decision the U.S. Court of Appeals for the District of Columbia circuit set aside the U.S. AEC's issuance of a provisional construction permit to PRDC for construction of their Enrico Fermi power plant, on the grounds that the safety of the plant was not proven, yet leave to operate would inevitably follow. The U.S. AEC is taking steps to have the decision tested and further long legal battles are imminent. Should the decision of the court be upheld work on the site will have to stop, if not indefinitely at least for a number of years. The U.S. AEC and the company are mustering their forces to fight the verdict but at present it is impossible to anticipate the outcome.

Charging Difficulties on G-2

During charging of the G-2 reactor at Marcoule the seal between the charge machine and a fuel channel failed and some of the coolant was lost. The reactor was immediately shut down and depressurized and no damage to fuel elements resulted. The discharge of CO_2 presented no health hazard and repairs were completed within 10 days. The reactor is now in operation again.

EDF-3 Tenders Being Studied

Tenders for the major components of EDF-3, the third of the company's gas cooled graphite moderated reactors, are now under study. Three incorporating a steel pressure vessel and three a concrete vessel are all of high merit and it will be some months before the evaluation can be completed. At first sight the designs for the concrete pressure vessel appear technically satisfactory but do not offer as large an economic advantage over the steel pressure vessel as could have been anticipated. Meanwhile the welding procedures adopted for the EDF-1 vessel appear to be working out satisfactorily and all but the last of the individual courses are now complete.

Contract for Chooz Station Expected Shortly

The announcement of the placing of the contract for the Franco-Belgian Euratom project at Chooz is expected within a week or two. Three tenders have been submitted by organizations each comprising one Belgian, one French and one American concern. These are for an organic reactor (A.I.), a BWR (G.E.) and a PWR (Westinghouse). Euratom is anxious to get an organic moderated project under way as soon as possible and it is expected that this will be the choice for Chooz.

Nuclear Safety Advisory Committee Established

An independent high powered committee to act in an advisory capacity to the Minister of Power as projected in the Nuclear Installations (Licensing and Insurance) Act has now been set up under the chairmanship of Sir Alexander Fleck. The committee of 23 members makes an impressive list of notabilities and includes representatives with widely different backgrounds. The weight of expert opinion should be vast and one trusts not unmanageable.

G.E. to Build 50 MW Reactor for Los Angeles

Under the U.S. AEC's power demonstration programme G.E. is to build under a fixed-price contract a 50 MW improved cycle boiling water reactor which will be operated by the cities of Los Angeles and Pasadena, California. The nuclear plant, for which the Commission will pay about $12\frac{1}{2}$ million, is scheduled for completion in mid-1963. It is to serve as a prototype for a 300 MW reactor and incorporates internal steam water separation and other features aimed at reducing power costs.

Senate Approves Euratom Occupation of Ispra

The Senate Foreign Affairs Committee in Italy has at last approved the bill which would ratify the Euratom Italian treaty covering the handing over of the Ispra research establishment to Euratom. The bill has now been passed to the Assembly, which is now unlikely to hold up the project. Euratom has had for many months a considerable staff ready to move to Ispra and begin immediate experiments but the hold-up in the ratification has caused serious dislocation both to the research programme and staff arrangements.

AEA to Build ZEBRA at Winfrith

To supplement the engineering and fuel element experiments at Dounreay the U.K. AEA has decided to build at Winfrith the Zero Energy Breeder Reactor Assembly, ZEBRA. This is being designed to permit the study of the neutron physics of a wide variety of fuel assemblies containing uranium and plutonium. The assemblies under study will be built up by loading fuel elements into a steel matrix approximating to a cube of 10 ft sides. Coolant will be simulated by inserting absorber plates. The facility is planned for commissioning during 1962.

General Atomics Establishes European Organization

General Atomics has announced the establishment of a new European-wide company to be known as General Atomic Europe with headquarters in Zürich but with branches also in Düsseldorf and Milan. General Atomics is currently engaged on the development of the high temperature gas cooled reactor and the European organization is designed to promote this particular system by incorporating European techniques and experience. Dr. Peter Fortescue, formerly of Harwell but latterly working in San Diego, has been appointed chief research and development engineer.

Allis-Chalmers to Build South African Reactor

Against heavy competition Allis-Chalmers has gained a contract for the construction of a materials testing reactor in South Africa. There has been keen bidding for this contract and the basic design specification has changed many times. In the light of the decision to set up fuel element manufacturing facilities it was concluded that a local test reactor was necessary in order to carry out loop experiments at high flux. The reactor will be an improved ORR designed for initial operation at 6.6 MW and eventually at 20 MW.

Reactor Briefs

India's NRX 40 MW materials testing reactor began operating on July 10 at Trombay. . . . The 100 kW TRIGA Mark II RC-1 reactor at the CNRN Nuclear Studies Centre at Casaccia went critical on June 10. . . . Israel's first reactor, a 1 MW pool type, achieved criticality on July 6. . . . The R2-O pool type reactor at Studsvik, Sweden, went critical on June 29.

1.—General Description

By L. MERGAN
(Centre d'Etude de l'Energie Nucléaire)

THE BR-3 reactor at Mol is of particular interest in that it is not only Belgium's first power reactor, but is the first pressurized water reactor in Western Europe. It is also the U.S.A.'s first " export " reactor, in the power field.

Although a descendant of Shippingport, the optimization is more concerned with the economics and it has many design features which differentiate it from its famous predecessor, amongst which may be mentioned: the low-enrichment uranium oxide fuel, the stainless steel cladding, the provision for boric acid cold shutdown, and the primary coolant loop layout. Its main purpose is to contribute to experience and operation of pressurized water nuclear power plants. It will also be used as a training station for operation personnel in preparation for larger units.

As is the case with most Belgian nuclear projects, its design, construction, and ownership are the result of collaboration between a number of different bodies, whose functions are explained in an accompanying article.

Ownership is vested in the Centre d'Etude de l'Energie Nucléaire (C.E.N.). The supplier and designer of the nuclear equipment and systems is the Westinghouse Electric Company, with Gibbs and Hill acting as Architect-Engineer for Westinghouse. The design and construction of the complete plant are the responsibility of the Bureau d'Etudes Nucléaires (B.E.N.) in co-operation with the Société Belge pour l'Industrie Nucléaire (BelgoNucléaire) and, for the conventional part of the plant, the Société de Traction et d'Electricité (T.E.). Engineers from B.E.N., BelgoNucléaire and C.E.N. have taken part in the studies made by Westinghouse. Construction started in November, 1957, and criticality is scheduled for the end of this year.

General Description of Scheme

BR-3 is a pressurized water reactor with a thermal rating of 40.9 MW, and an electrical output of 11.5 MW (gross) and 10.7 MW (net), generated by a single turbine with dry saturated steam at 520 p.s.i.a. and 471°F. A moisture separator is provided between the two sections of the turbine. Feedwater is heated to 325°F by two surface preheaters and one deaerating heater.

The complete arrangement of the plant, shown on the pull-out drawing, may be subdivided into the following buildings:

The **Plant Container** houses the pressure vessel, the primary coolant loop, the steam generator and the pressure control system. It is a vertical steel shell 107 ft high, 54 ft 3 in. diameter and 1¼ in. thick, founded in a concrete slab surrounded by a circular sheet piling, one-fourth being below ground level. It is designed to resist the pressure build-up (45 p.s.i.g.) resulting from the maximum credible accident and to contain the fission products which might be released, and has a concrete liner to limit the accidental radiation dose in the vicinity. All piping penetrations are protected by a double set of remotely operated valves or check valves located on both sides of the steel shell.

The **Storage Well** building provides storage for used fuel elements and control rods.

The **Auxiliary** building houses the main reactor plant auxiliary systems and some other facilities: hot and cold lockers, water sampling room, hot laboratories, shipping area, storage space, etc.

The **Waste and Ventilation** building houses the main liquid and gaseous waste hold-up equipment, the main ventilation equipment and the two refuelling canal water storage tanks.

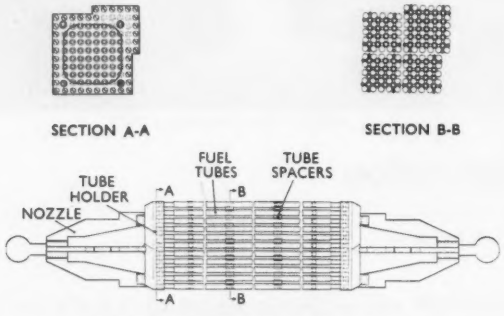
The **Turbine** building houses the steam and electric plants, the control room, the emergency diesel generator set and other plant auxiliaries.

The **Office** building provides office space and normal access to the plant.

Core

The core, which is dealt with in more detail elsewhere in this issue, approximates the shape of a cylinder 33.6 in. diameter and 56 in. high giving a length-to-diameter ratio of 1.67. It has a cross section which can be regarded as roughly cruciform, or a square with cutaway corners, made up of 32 square channels, arranged in rows of 4-6-6-6-6-4. Each channel contains a fuel element of approximately square section, with portions cut away to allow clearance for the blades of the cross-shaped control rods which are disposed at the centre of the square formed by four fuel elements, i.e., arranged in five rows of 2-3-2-3-2 rods. To accommodate this geometry, there are two types of fuel elements, with slightly different cross-sections. The core cage, support plates, baffles and barrels, like all other internal parts of the pressure vessel, are made of type 304 stainless steel.

The fuel elements are made up of type 348 stainless steel tubes 0.343 in. in outer diameter and 0.021 in. thick, there



General arrangement of fuel element.

being 110 or 111 tubes per element, according to the geometry. The inner volume is filled with uranium oxide pellets 0.300 in. diameter and 0.600 in. high. Fuel density is 93% of theoretical. Each fuel element is made up of four sub-assemblies. The sub-assembly consists of a bundle of fuel rods joined together by brazed tubular stainless steel ferrules, to provide the proper spacing between rods and to furnish the required structural rigidity to the assembly. Fuel elements are symmetrical and may be turned upside down to equalize burn-up, the flux being reduced in the upper part of the core due to the movement of the control rods.

The core is enriched in two zones, the outer 16 elements being 4.43% and the remaining inner elements 3.7% enriched, giving a better radial power distribution and enabling preliminary half-core critical experiments to be carried out with the higher enrichment. The designed core life is 7,000 hours at full power.

The fuel assemblies are supported between end plates provided with holes for coolant flow and cross-shaped slots for control rods. As the fuel elements form an open lattice, the coolant flow is not modified by grading nozzles. Power flattening is obtained by the dual-zone enrichment and judicious control rod programming.

The reactor core is surrounded by a form-fitting baffle which confines the flow within the fuel-bearing zone, and water flowing between the baffle and the barrel acts as a reflector.

Four high-flux specimen tube assemblies are located between the core baffle and core barrel. The tube

Cutaway view of reactor.

assemblies are spaced at 90° intervals around the core. The tubes are used for the irradiation of test specimens of the reactor vessel material in order to determine the progressive effects of radiations on the mechanical properties of this material. Specifically, the tube assemblies are

The

TYPE:	T
LOCATION:	M
PURPOSE:	P
OWNER:	C
ARCHITECT ENGINEERS:	B S S
MAIN SUPPLIER:	W A
STATUS:	C C
OUTPUT:	4
FUEL:	E T
CORE:	C ch pl A A 5 p t k M N
	T
FUEL ELEMENTS:	T c (1 C
CONVERSION FACTOR:	Ir
BURN-UP:	5,
CONTROL:	Si (1 N 1
	S
COOLANT:	P C C N H C H m M C
PRESSURE VESSEL:	C C H T D
HEAT	U

The World's Reactors

No. 27 BR3

Thermal heterogeneous (PWR).

Mol, Belgium.

Power Experiment.

Centre d'Etude de l'Energie Nucléaire (C.E.N.).

Bureau d'Etudes Nucléaires (B.E.N.).
Société Belge pour l'Industrie Nucléaire (BelgoNucléaire).
Société de Traction et d'Electricité (T.E.).

Westinghouse Electric International Company (Gibbs and Hill, Architect Engineer for Westinghouse).

Construction commenced November 1957.
Criticality scheduled for the end of 1960.

40.9 MWt, 11.5 MWe (gross), 10.5 MWe (net).

Enriched uranium oxide (inner zone 3.7%; outer zone 4.43%).
Total loading at rated power 2,000 kg U.

Cruciform prism 31.68 in. (80.5 cm) square, composed of 32 channels arranged in rows of 4-6-6-6-6-4 at 5.28 in. (13.41 cm) pitch.
Active height: 56 in. (142 cm).
Average power density: 50.45 kW/litre.

ξ=1.034.	Excess reactivity for:
ρ=0.81.	Temperature 9%.
τ=50 cm².	Xe and Sm 5%.
keff (hot, clean)=1.097.	Burn-up 5%.
Maximum excess reactivity, cold, clean	19%.

Neutron flux:
Thermal average: 1.8×10^{13} n/cm², sec.
Thermal maximum: 5.1×10^{13} n/cm², sec.
Fast, average: 1.1×10^{14} n/cm², sec.
Fast, maximum: 2.7×10^{14} n/cm², sec.
Temperature coefficients:
Fuel: -2 to $-5\times10^{-5}\ \frac{\Delta k}{k}$/°F ($-3.6$ to $-9\times10^{-5}\ \frac{\Delta k}{k}$/°C).
Moderator: -2 to $-4\times10^{-4}\ \frac{\Delta k}{k}$/°F ($-3.6$ to $-7.2\ \frac{\Delta k}{k}$/°C).

Two types, 111 and 110 rods, each rod 0.343 in. (0.87 cm) diameter, containing 91 pellets 0.300 in. (0.76 cm) diameter × 0.600 in. (1.52 cm) long.
Cladding: type 348 stainless steel, 0.021 in. (0.053 cm) thick.

Inner region 0.469; outer region 0.435.

5,940 MWd/t (average).

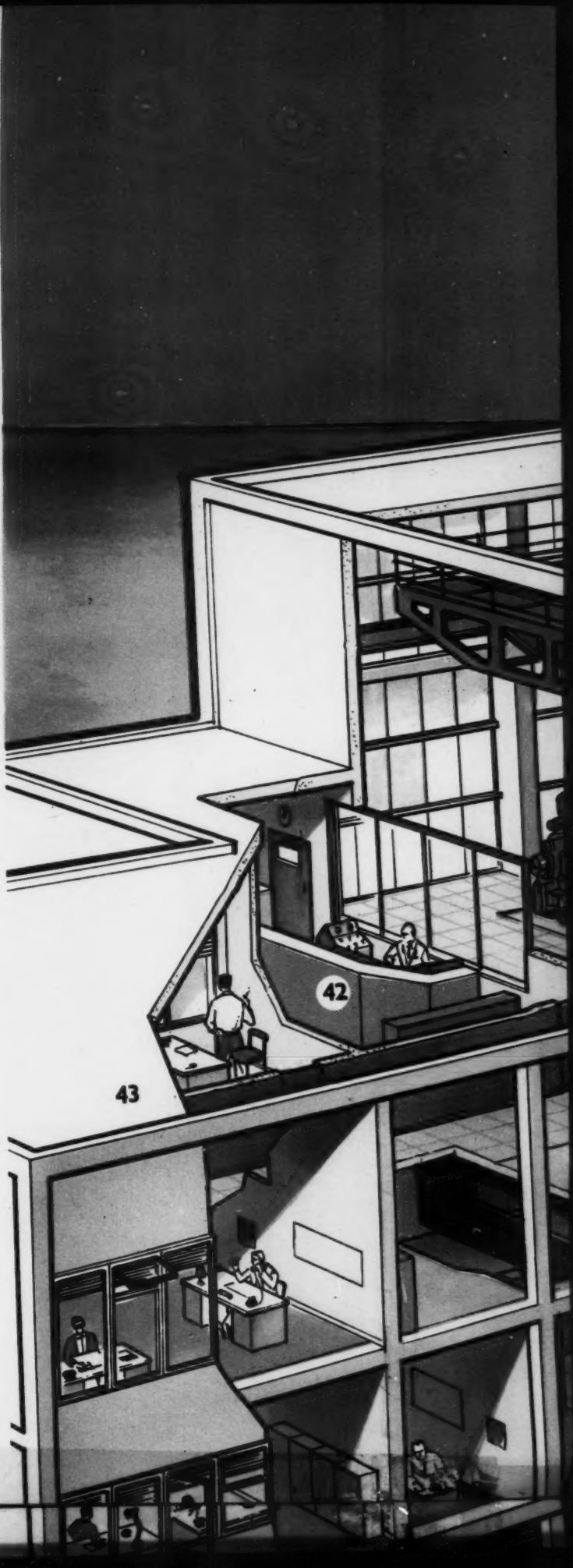
Silver-indium-cadmium rods of cruciform section, 5.19 in. (13.18 cm) square × 0.250 in. (0.635 cm) thick.
No. of rods: 12. Active length 56.75 in. (144 cm). Overall length: 122.44 in. (311 cm). Total worth of control rods: 20% $\frac{\Delta k}{k}$.

Scram time 0.15 sec.

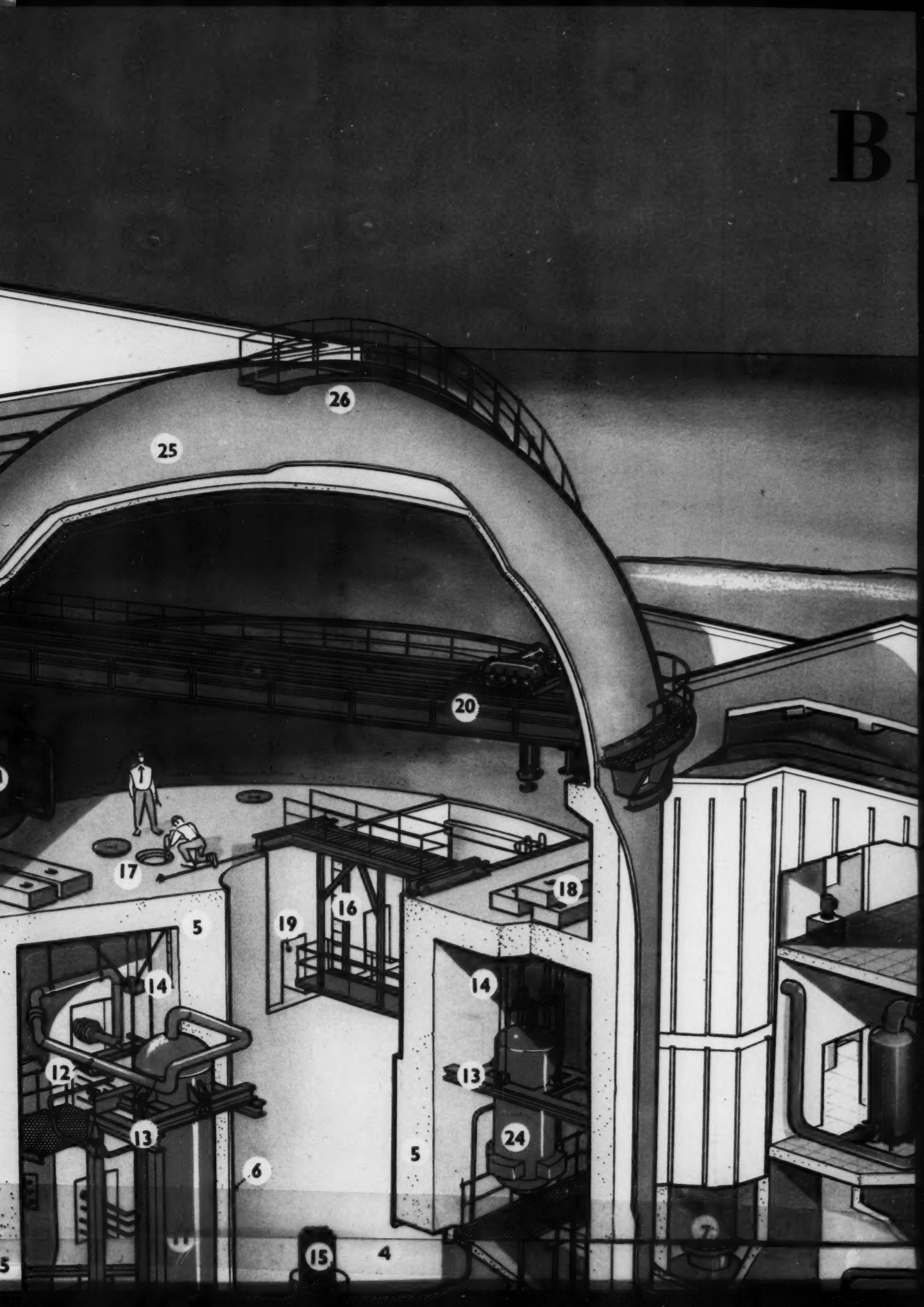
Pressurized water. Inlet temperature: 491°F (255°C).
Outlet temperature: 515°F (268°C). Hottest channel: 586°F (308°C).
Coolant pressure: 2,000 p.s.i.a. (140.6 Kg/cm² abs).
Mass flow: 5×10^6 lb/h (2,268 Metric T/h).
Heat transfer area: 1,482 ft² (137.7 m²).
Channel velocity: 7.7 ft/sec (2.35 m/sec).
Heat transfer coefficient: 3,440 B.t.u./hr, ft², °F (16,800 *k* cal/hr, m², °C).
Maximum fuel element temperatures: Fuel: 3,930°F (2,166°C).
Cladding: 657°F (347°C).

Carbon steel, clad internally with stainless steel.
Outside diameter: 5 ft 7 in. (170 cm).
Height: 18 ft (549 cm).
Thickness: 4.5 in. (11.4 cm).
Design pressure: 2,500 p.s.i.a. (175.8 Kg/cm² abs).

U-tube type, with stainless steel tubes.
Heating surface: 4,220 ft² (392 m²).
Feed temperature. 325°F (163°C).
Steam flow: 154,500 lb/h (70.1 Metric T/h).



38
37
39
40
36
35
41
21
17
22
45
47
46


B
26
25
20
1
17
18
16
19
5
14
14
12
13
13
24
5
6
7
15
4
5

BR3
28
29
7
33

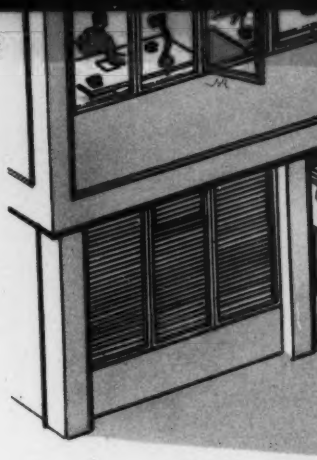
48
30
29

Feed temperature. 325°F (163°C).
Steam flow: 154,500 lb/h (70.1 Metric T/h).

SHIELDING: Internal stainless steel thermal shield, 3 in. (7.62 cm) thick. Biological shielding of barytes concrete (density 3.4) to a minimum thickness of 3 ft 10 in. (1.17 m).

CONTAINMENT: Cylindrical steel building, with spherical roof. Outside diameter: 54 ft 3 in. (16.54 m). Overall height: 107 ft (32.6 m). Thickness: 1.12 in. (2.85 cm). Design pressure: 45 p.s.i.g. (3.16 Kg/cm² eff). Test pressure: 57 p.s.i.g. (4 Kg/cm² eff).

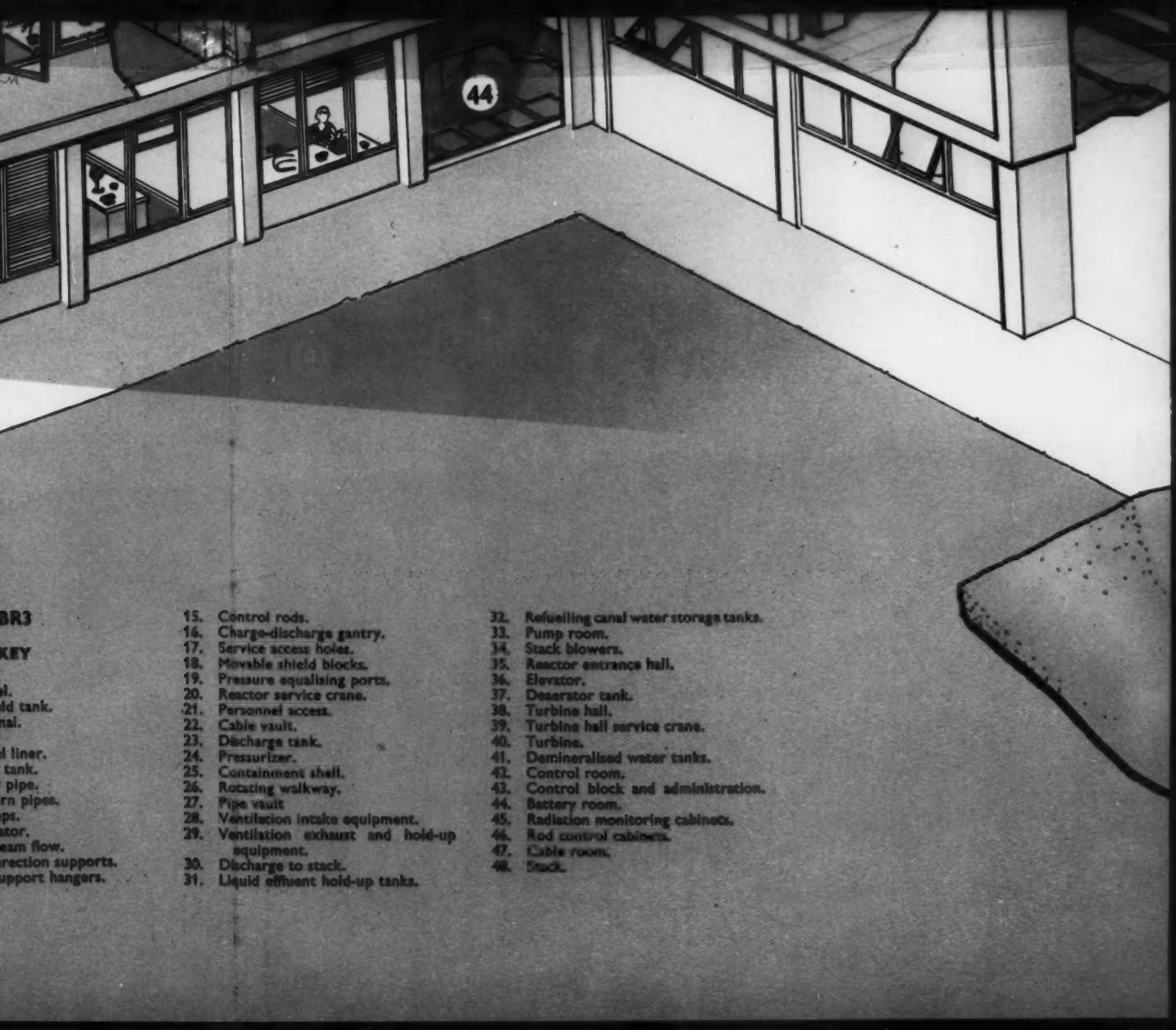
© TEMPLE PRESS LIMITED, 1960.



BR3

KEY

1. Core.
2. Reactor vessel.
3. Neutron shield tank.
4. Refuelling canal.
5. Shield walls.
6. Stainless steel liner.
7. Fuel transfer tank.
8. Primary flow pipe.
9. Primary return pipes.
10. Primary pumps.
11. Steam generator.
12. Secondary steam flow.
13. Temporary erection supp
14. Permanent support hang



BR3

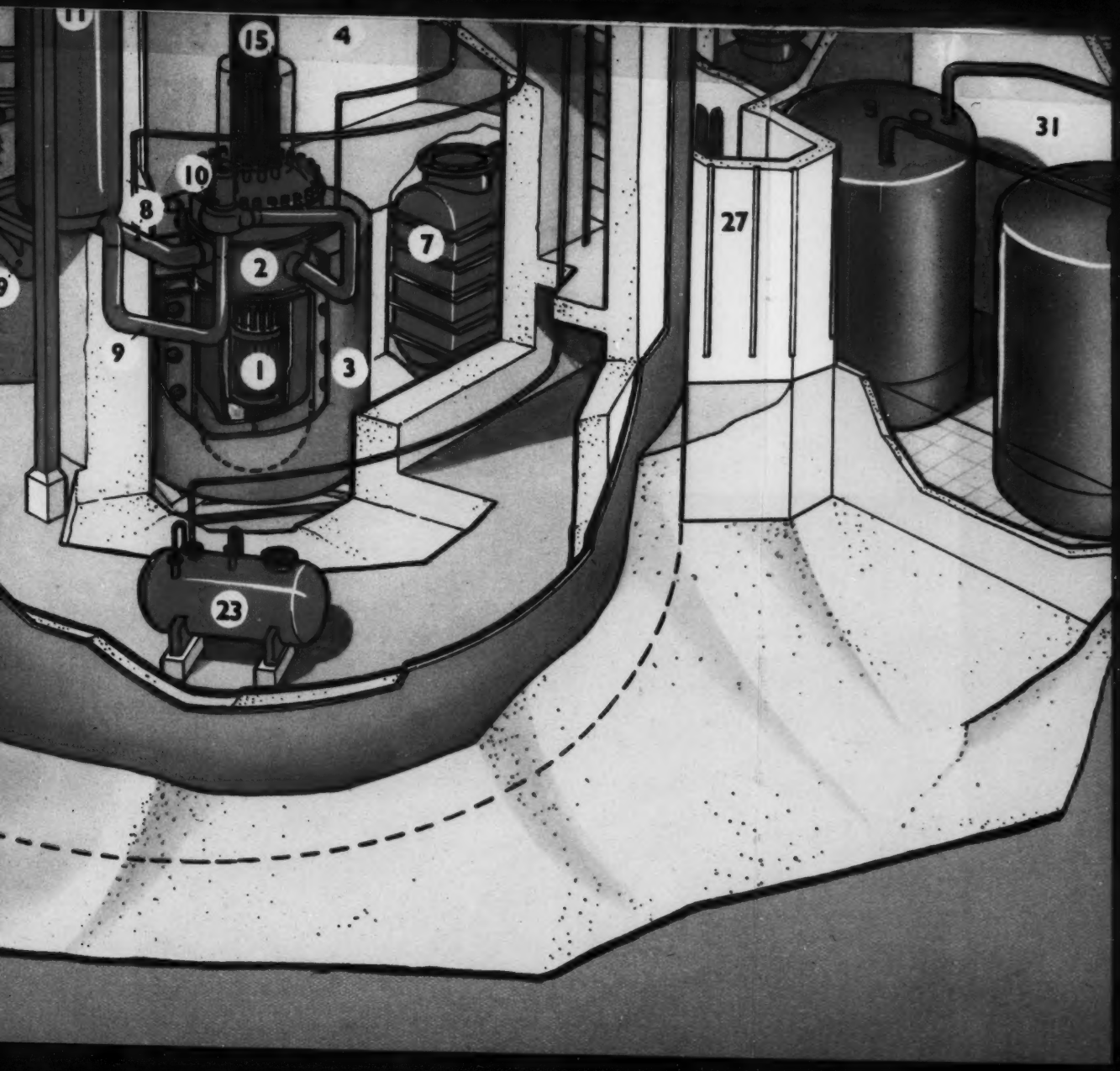
KEY

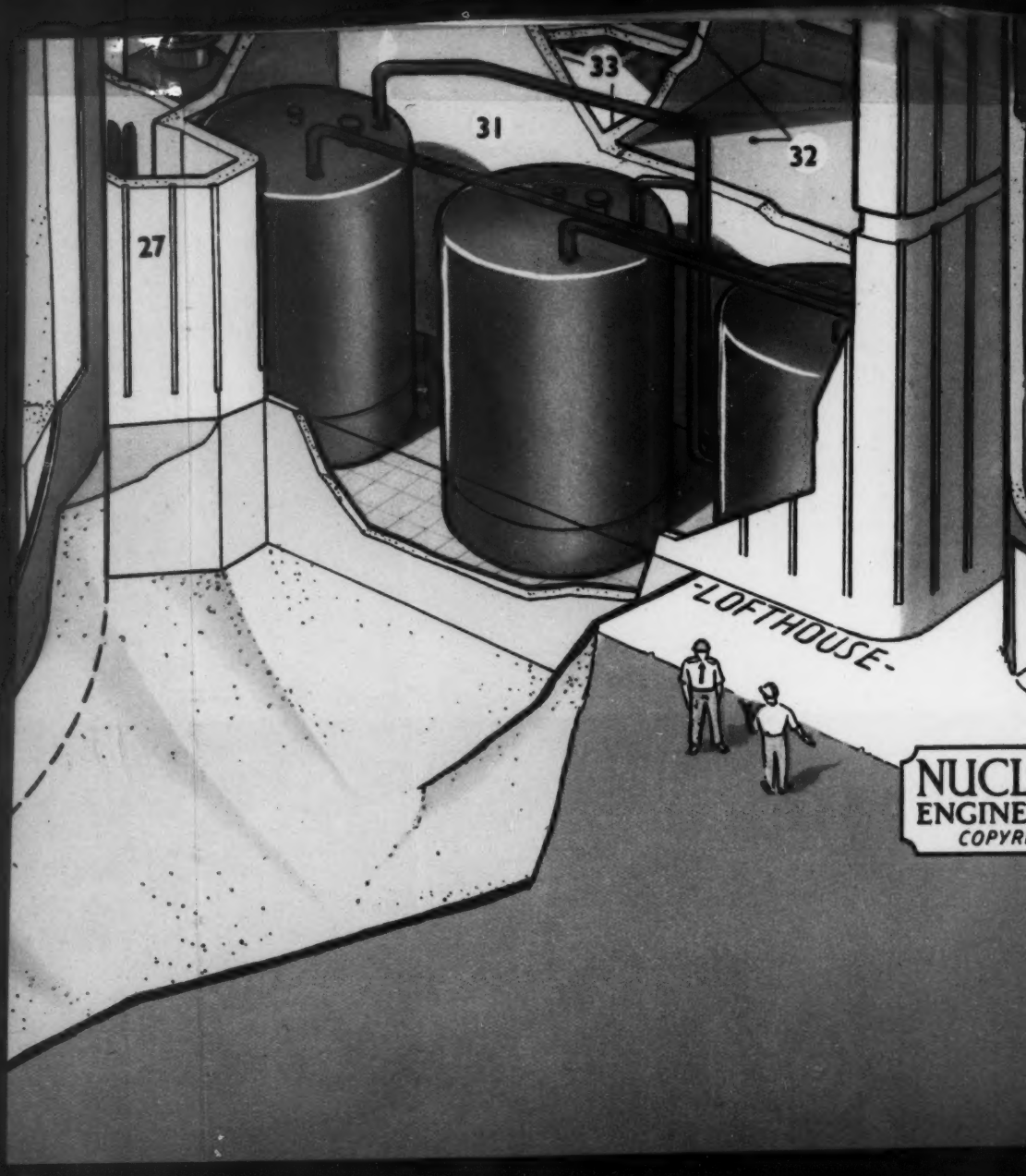
...l.
...ld tank.
...nal.

...l liner.
... tank.
... pipe.
...rn pipes.
...ps.
...tor.
...eam flow.
...rection supports.
...upport hangers.

15. Control rods.
16. Charge-discharge gantry.
17. Service access holes.
18. Movable shield blocks.
19. Pressure equalising ports.
20. Reactor service crane.
21. Personnel access.
22. Cable vault.
23. Discharge tank.
24. Pressurizer.
25. Containment shell.
26. Rotating walkway.
27. Pipe vault
28. Ventilation intake equipment.
29. Ventilation exhaust and hold-up equipment.
30. Discharge to stack.
31. Liquid effluent hold-up tanks.
32. Refueling canal water storage tanks.
33. Pump room.
34. Stack blowers.
35. Reactor entrance hall.
36. Elevator.
37. Deaerator tank.
38. Turbine hall.
39. Turbine hall service crane.
40. Turbine.
41. Demineralised water tanks.
42. Control room.
43. Control block and administration.
44. Battery room.
45. Radiation monitoring cabinets.
46. Rod control cabinets.
47. Cable room.
48. Stack.

5
10
9


15
4
31
10
8
27
7
2
9
1
3
23


33
31
32
27
-LOFTHOUSE-
NUCL
ENGINE
COPYR

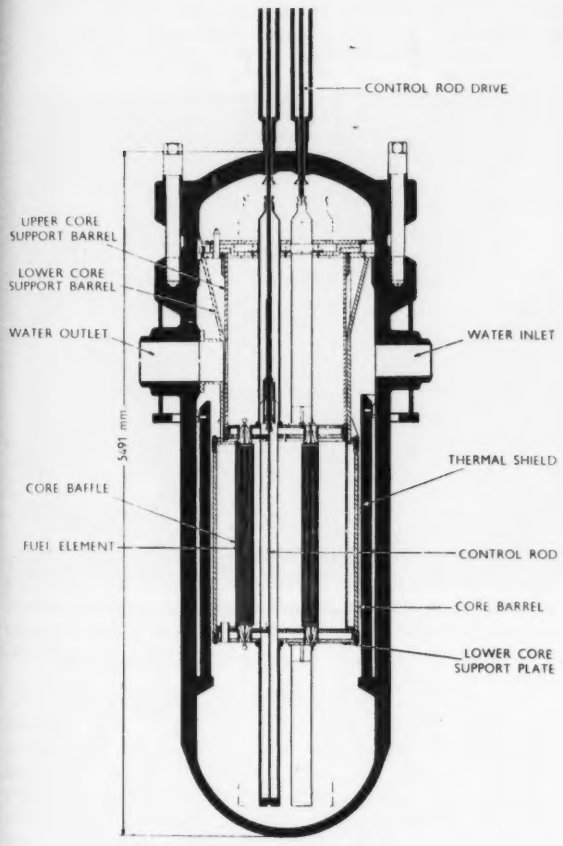
34
NUCLEAR
NGINEERING
COPYRIGHT

provided for tensile and Charpy V-notch impact specimens.

The polonium-beryllium primary neutron source is mounted on a movable vane extending into the core, at the edge of the core baffle. This primary source is surrounded on the same vane by two secondary antimony-beryllium sources which are activated by flux irradiation.

Control

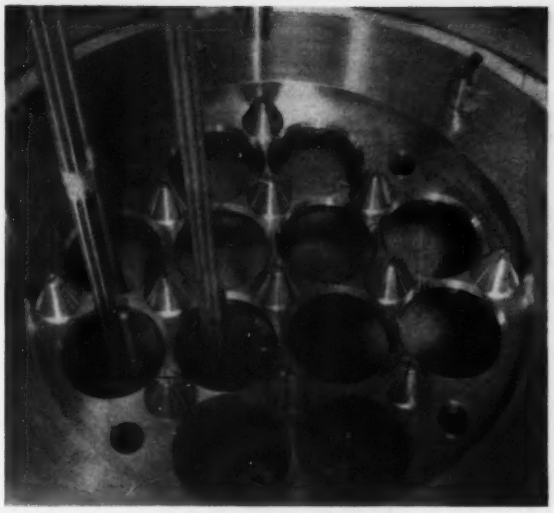
There are 12 cruciform rods of a silver-indium-cadmium alloy (80% Ag, 15% In, 5% Cd) which is "black" to neutrons, fitted with long extensions of Zircaloy-2 which act as guides, and fill the space when a control rod is withdrawn, preventing formation of "water holes" and the consequent flux peaking. The neutron-absorbing part of the rod is nickel plated.



Vertical section of reactor.

Each rod is raised and lowered by an individual mechanism of the "magnetic jack" type. The lifting rod consists of a bundle of flexible steel rods which diverge slightly under a magnetic field and grip the bore of one of two plungers, one being fixed, and the other capable of being moved up or down (by steps of about $\frac{1}{4}$ in.) under the influence of other magnetic fields. This mechanism is completely enclosed in a leak-proof stainless steel container screwed and welded to the pressure vessel, and operating under full primary pressure, so that there are no glands to cause leakage.

A series of magnet coils, external to the mechanism tube, and therefore protected from the primary coolant, alternately cause the rod bundle to attach itself to either the fixed or moving plunger, so that it "ratchets" up or



Lifting rod bundles for control rods.

down in a series of small movements, the correct sequence for the holding and moving magnet coils being programmed by a motor-driven cam controller through contactors, the rod being limited to a safe speed of 6 in. per minute.

Position indication is given by a series of pick-up coils above the operating mechanism which, in effect, "sense" the position of the rod through the change in magnetic reluctance due to the movement of the rod causing a variation of impedance in the coil circuits.

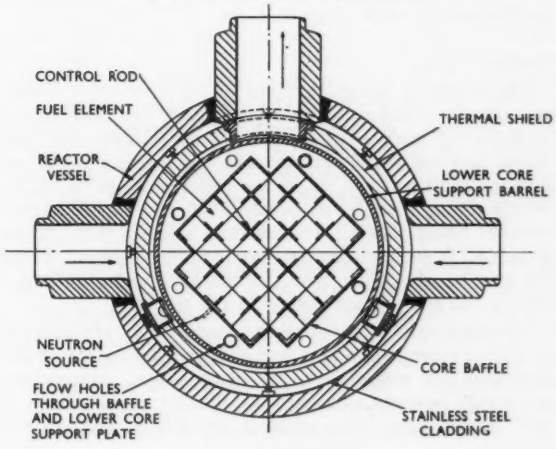
An important safety feature of this type of mechanism is the ability to scram the control rods at any time by de-energizing the coils. Another feature ensuring reliability is that each operating cycle tests the ability of the mechanism to scram when the coils are de-energized. A hydraulic dashpot backed up by a spring shock absorber prevents mechanical damage to a control rod at its end of travel, in case of scram.

For refuelling purposes the control rod drive mechanisms are disengaged from the control rods, leaving them fully inserted in the core.

Pressure Vessel

The pressure vessel is in carbon steel with stainless steel cladding. The outside diameter is 5 ft 7 in. and the overall

Horizontal section through reactor.



height including lid is 18 ft. Design pressure and temperature are 2,500 p.s.i.a. and 650°F respectively.

The cylindrical portion of the vessel is made of 4¼ in. carbon steel clad with 0.109 in. thick type 304 stainless steel by resistance welding. The inside diameter is 58 in. to the cladding. The spherical bottom is 2¾ in. thick carbon steel, lined with stainless steel which is arc deposited.

Two inlet nozzles are located in the upper portion of the shell 180° apart, and one outlet nozzle is located between them at the same elevation. Thirty-two 4¼ in. studs secure the head to the vessel. The flange surface is sealed by means of two O-ring gaskets and a seal weld may be used. The vessel is insulated up to the bolting flange by 4 in. thick Fibreglass.

A cylindrical, stainless steel thermal shield, 3 in. thick, 7 ft 4 in. high, rests on four supports near the bottom of the vessel and two thin stainless steel barrels, supported on a ledge near the vessel top flange, are designed for supporting and holding down the core and directing the coolant flow.

The fast neutron flux at the inside wall of the pressure vessel (attenuation of approximately a factor of 10 through the wall), integrated over 20 years of reactor operation, is calculated to be 10^{20} n/cm².

Coolant Circuit

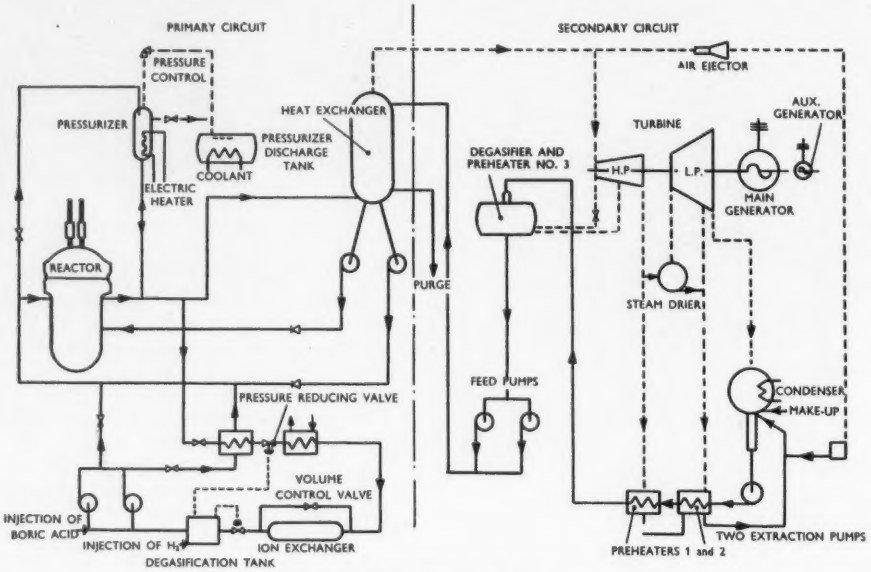
Main coolant water at 2,000 p.s.i.a. and 491°F enters the reactor vessel at a level just below the bolt flange, through the inlet nozzles, flows down between the core barrel and the vessel wall around the thermal shield, up through the core, and leaves the vessel through the outlet nozzle at an average temperature of 515°F, the hottest channel being 586°F. The average velocity through the core is 7.7 ft/sec and the mass flow is 5,000,000 lb/hr. From the reactor, the water flows to the heat exchanger, then returns via the coolant pumps to the reactor.

The main coolant circulating pumps, which are installed in each of the two return legs to the reactor, are of the canned-motor single-stage centrifugal type, with water-lubricated bearings, designed to operate continuously at any temperature from ambient to 650°F and at any pressure from 200 p.s.i.a. to 2,500 p.s.i.a. The design head is 50 p.s.i.

A check valve, installed in the pump volute, at the inlet of each coolant pump, is used to restrict reverse flow in the event of pump failure. These valves are of the spring-loaded, centre-guided, lift type, with small holes in the disc to allow a slight reverse flow for equalization of temperature and poison concentration in the idle leg.

Main Heat Exchanger

The main heat exchanger, or steam generator, is a vertical cylinder, approximately 5 ft × 26 ft overall, containing 1,400 ⅝ in. U-tubes of 304 stainless steel for the primary water, the heat transfer surface being 6,220 ft². All shell and tube-plate surfaces in contact with the primary coolant are stainless steel clad. The primary water enters through a stainless steel pipe, 16 in. o.d., and returns through two 12-in. o.d. pipes.



Simplified flow diagram of system.

Natural convection is used for the secondary water, the feedwater entering the drum at 325°F, and flowing downwards in the annular space between the shell and a wrapper around the tube bundle; it enters the heat exchange area near the tube sheet at the bottom, and flows upwards in a parallel-flow pattern. Moisture is separated at the top in three stages including centrifugal- and chevron-type vane and plate separators. Dry, saturated steam is produced at a rate of 154,500 lb/h at full load, the designed maximum being 161,500 lb/h. The design pressures are 2,500 p.s.i.a. primary and 900 p.s.i.g. secondary.

Pressure Control System

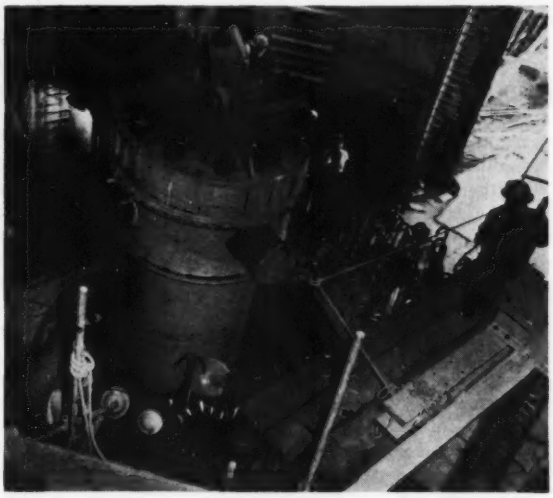
The functions of the pressure control and relief system are: to maintain pressure in the main coolant system during steady-state operation; to absorb volume changes of the main coolant system and limit pressure surges during normal plant load transients; to provide overpressure protection for the main coolant system.

A pressurizer vessel, connected to the main coolant system, contains a two-phase mixture of water and steam at a temperature of 636°F, the saturation temperature at 2,000 p.s.i.a. Electric immersion heaters generate steam in

the top and an intermittent spray is provided to condense steam during positive surges and thus limit the pressure rise. Pressure is kept above the lower limit during negative surges by the flashing of steam from the water.

The net internal volume of the pressurizer is 93.2 cu. ft. The nominal minimum water level is 12 in. above the top row of the heaters, which automatically de-energize if the level falls below this point. Design conditions are 2,500 p.s.i.a. and 668°F. All material in contact with the primary coolant water during normal operation is type 304 stainless steel. Ninety 1,700 W replaceable-type immersion heaters are installed, each heater being mounted in a well so that replacement may be made without depressurizing or draining the vessel.

Protection is provided by two safety and two relief valves, the relief valves being set at a lower value than the safety valves, and capable of remote operation from the control room. Discharge is led to a discharge tank, which can be drained to the waste hold-up system.



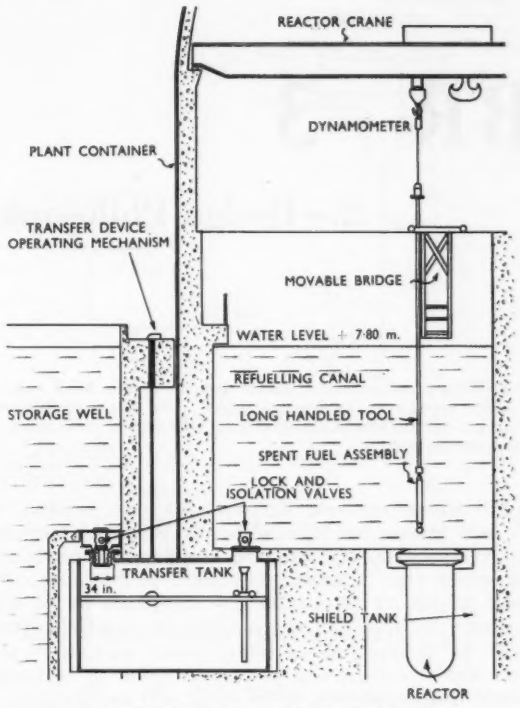
General view of pressure vessel during erection.

The discharge tank has been designed to condense and contain the discharge of the pressurizer safety and relief valves and steam generator (secondary side) safety valves. These valves discharge into a closed vent system terminating in a sparger located in the bottom of the discharge tank. This tank has an internal volume of 300 cu. ft and will normally be half full of water at ambient temperature (122°F). It is designed for a pressure of 50 p.s.i.g. and is provided with a rupture disc allowing discharge of the steam in the plant container.

Purification System

One of the major primary auxiliaries is the purification system which is designed to remove the corrosion products formed at a rate of 10 mg/dm² month and the fission products released to the coolant on the assumption that 1% of the fuel rods are defective and that the release of each fission product is proportional to its concentration.

The purification system is a low pressure arrangement consisting of a regenerative heat exchanger, a pressure-reducing station and a non-regenerative heat exchanger, two demineralizers in parallel (one for normal operation, one for the removal of boric acid after the feed and bleed operation during a cold starting), one surge tank and two high-pressure charging pumps.



Simplified diagram of refuelling arrangements.

The main coolant flow through the purification system, which is a by-pass of the main loop, is set at 6 gal/min. Continuous operation of the purification is not vital to plant operation. The system can be isolated and the resins replaced with the demineralizer without interfering with the plant operation. The resins require a water temperature below 150°F. In operation the temperature will be 120°F at 120 p.s.i.a.

The major part of the system is located outside the vapour container in a shielded and limited access area in the basement of the auxiliary building.

Refuelling Procedure

Refuelling takes place with the canal flooded to a total depth of 22 ft, the reactor head being removed and the elements removed by means of special tools and fixtures, from a movable bridge. The spent fuel elements are then passed, under water to the storage well, through the transfer tank, which passes through the container wall and is fitted with 10 in. valves at either end. Passage through the tank is effected by means of a transfer mechanism, consisting of a cable-driven trolley carrying a container which, under remote control, conveys the elements from one valve to the other. Irradiated elements are left in the tank until sufficient decay in activity has occurred to permit them to be sent away for reprocessing in a shielded container. Replacement elements and control rods are brought on to the operating floor in their shipping containers.

Besides the main reactor systems and components which have been described in some detail, many reactor auxiliary circuits are provided whose description is beyond the scope of this article. They are the corrosion inhibition system, the component cooling system, the shutdown cooling system (normal and emergency), the safety injection system, the charging system, the waste disposal system, the vents and drains system and the sampling system.

BR—3

2.—Design Philosophy and Plant Construction

By P. ERKES
(Deputy Manager, Bureau d'Etudes Nucléaires)
and G. TAVERNIER
(Manager, BelgoNucléaire)

This article describes some special features of the BR-3 reactor, a general description of which appears in the previous pages. The first part deals with the design philosophy leading to certain special characteristics; the second part, some interesting features of the actual construction.

THE general concepts of pressurized water reactors are well known, but there are many aspects of a specific project—purpose, size, fuel and cladding, site conditions, etc., which must be taken into account in the design. The main purpose of BR-3 is to give experience in the construction and operation of a power-producing PWR which could be extrapolated to future power stations of this type, and it is interesting to consider some of the fundamental features peculiar to its design and construction.

Core Design

Data on the construction and characteristics of the core appear in other articles in this issue. It may be interesting to explain briefly the control problem and the limitations which have led to the actual design with two regions of different enrichments.

A low-enrichment PWR with a large negative temperature coefficient raises difficult problems of control due particularly to the large variations of reactivity when going from cold to hot. The use of oxide fuel which is brought, at full power operation, to a higher temperature than a metallic fuel, also increases the reactivity variation due to the Doppler effect. Approximately 19% excess reactivity must be provided in the clean cold core in order to remain critical at operating temperature with equilibrium poisons present at the end of the 7,000 hours life. This excess reactivity requirement may be broken down as follows:

Cold to hot (zero power)	7%
Doppler effect in fuel (from zero power to full power)	1-2%
Equilibrium xenon and samarium	5%
Fuel burn-up	5%
Total	19%

To this amount must be added a safety margin of about 5% to assure that the reactor can be made subcritical at room temperature. The total control range needed is, therefore, around 24%.

In any reactor of this type, it becomes a problem to provide this amount of control entirely by means of mechanical control rods. The problem becomes more acute if one considers that, when stainless steel is used as a cladding material, the fuel enrichment must be increased and the worth of a given control rod material and configuration is significantly less than when low cross-section materials, such as zirconium or aluminium are used for cladding.

For these reasons and to be sure that enough control will be available, a chemical shut-down system has been added to the control scheme. This system uses boric acid as soluble poison in the primary coolant water, and is designed to hold the reactor subcritical in a clean condition during cold shut-down.

Furthermore, an additional design requirement was that the core could be controlled with any one control rod remaining stuck out of the core. As central control rods have relatively more worth, this requirement led to a choice of a pattern with four rods at an equal distance from the centre rather than with a centrally located rod.

The core enrichment had to be specified to meet the two following conflicting requirements:

to get enough reactivity to obtain the specified core design life of 7,000 hours at full power with equilibrium xenon and samarium;

to provide enough control with a sufficient negative temperature coefficient, even with one central control rod stuck out.

These opposite conditions reduced the zone of acceptable tolerances on the reactivity and enrichment specifications. For this reason the enrichment was specified in two steps and it was decided that the core would be in two regions, offering the additional advantage of a better radial power distribution when the higher enrichment is located outside. A first half-core, enriched at 4.43% was manufactured, and used to perform a series of critical experiments which enabled the enrichment of the inner region (3.7%) to be specified more accurately.

If in the future it is deemed desirable to use cores of higher reactivity in order to increase the lifetime, the availability of the boric acid shut-down system will provide the additional control required and will avoid opening the vessel to change the core configuration.

Plant Control

A first study of the response of the reactor plant to change in load demand was made in mid-1957, at a time when many of the nuclear and thermal characteristics of the core were not yet fully calculated. This study served as an aid in the selection of certain plant components, such as the primary loop pressurizer and the relief and safety valves. It was also needed to determine the overall philosophy to be followed. A second study bore out the desirability of automatic reactor control to respond to load changes, and this was the subject of a third study.

These studies showed that, following severe load changes, rather large temperature and pressure excursions would occur in the main coolant and secondary systems, if there were no compensating movements of control rods. The times involved for these were in the order of minutes and a reasonably alert operator could probably reduce them considerably by manual rod movement.

However, for operational convenience, it was decided to adopt some relatively simple form of discontinuous automatic control, based on the average temperature of the core (which is maintained constant) and on a power differential control actuated by the difference between the core power (as measured from the neutron flux) and the load demand power (as measured from the steam flow). The average temperature control is adequate for moderate load changes; it is supplemented by the power differential control to take care of large step or fast ramp changes.

Coolant Loop Layout

As the BR-3 reactor is of relatively low power capacity (40.9 MWt), only one steam generator is needed to extract the power generated.

When the reactor is "scrammed" from full power, around 7% of the full load heat continues to be released, the rate decaying with time. Thus the water circulation must in any case be maintained, especially during the first few minutes, to prevent core melting and fission product contamination of the primary loop. As it may be dangerous to rely too much on natural circulation, two separate main coolant pumps, fed by two independent sources are necessary. In order to save piping, nozzles and associated equipment, a compromise between one and two primary coolant loops has been chosen, with only one hot leg and two cold legs, each containing a main coolant pump. To eliminate primary isolating valves, which are large units and could become a cause of leakage, one spring-loaded check valve is used in each of the cold legs, mounted in the pump volute and closing on reverse flow. Small holes are, however, provided in the discs of these valves to permit a designed leak rate in the reverse direction. The purpose of this reverse flow is twofold:

to maintain sufficient circulation in the inactive leg to prevent appreciable temperature drop so that, if the pump should re-start, the core would not be shocked by an influx of cold water which could increase the reactivity dangerously;

to assure, in case of chemical shut-down with boric acid diluted in the water, that the poison concentration in the idle leg remains the same as in the active one,

and thus obviate a start-up accident should the idle pump start again.

One pump is supplied from the station busbars, while the other is fed from an auxiliary 500 kVA generator, provided specifically for that purpose, driven by the main generator through a reduction gear and independently excited from a battery. If power from both sources should, by some very remote accident, be lost simultaneously, there is enough stored energy in the rotating parts of the turbogenerator to keep the auxiliary generator operating for at least 8 min during a coast-down from 215 kW at 50 cycles to about 40 kW at 10 cycles per second. This assures that the stored heat following a scram will be carried away and damage to the core will thus be prevented. For start-up and test purposes, the pump normally fed by this generator may be tied to one section of the 3 kV main busbar through a step-down transformer.

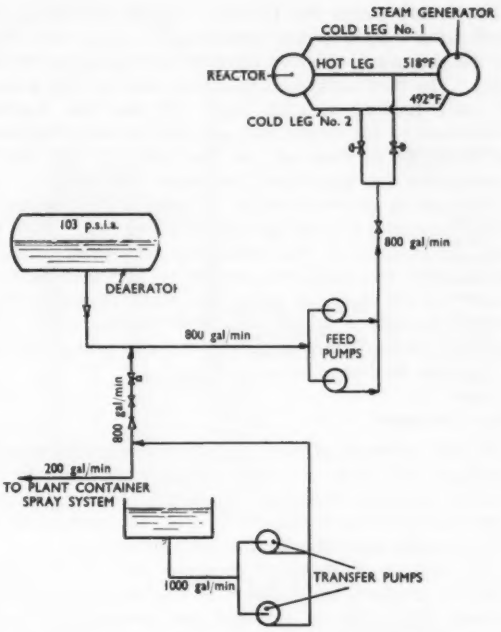


Fig. 1.—Simplified diagram of boric acid injection system.

The reactor pressure vessel has been designed so that inlet and outlet nozzles are all located well above the top of the core, which is a low point of the primary coolant circuit so that, should a leak occur, the core will not dry out.

To reduce thermal expansion stresses in the primary piping and equipment, the pressure vessel is the only fixed point of the system. The steam generator and primary coolant pumps are suspended from the top by means of spring hangers.

Safety Injection System

The possibilities and consequences of a loss of coolant accident have been thoroughly investigated. This may be caused by a rupture in the coolant system so that the pressurized water is blown off. The variations of pressure and weight of water remaining in the main coolant system have been computed in case of rupture of pipes of different diameters. In order to prevent core melt-down in this unlikely event, a safety injection system is provided to feed borated water to the core, thus lowering the pressure and rate of flow through the fault, as well as keeping the core covered. The safety injection system is started manually after receiving a pressure warning signal of 800 p.s.i.a., and has a capacity of about 780 gal*/min (108 lb/sec) at 520 p.s.i.a.

The system is designed to use initially the secondary feed pumps, which offers the advantage that one of them is continuously running and can instantly supply the safety injection system if necessary.

Two transfer pumps supply borated water, stored in the two 4,500 cu. ft. refuelling canal water storage tanks, upstream of the feedwater pumps and give an additional boost in pressure. To ensure that there will be a sufficient quantity of boric acid injected, a tank containing 325 gal of 10% solution is in a stand-by position.

*All gallons are in U.S. units.

The water enters the primary coolant system via the purification system piping through two pipes, one to the hot leg and one to the cold leg downstream of the primary pump. The flow instrumentation will indicate the amount of water flowing to each leg. If the flow becomes unbalanced to the extent that one flow is twice the other, the high one is shut off, so that solution will not be injected into the leg nearest the break.

The capacity of two 4,500 cu ft tanks is sufficient to last around one hour at 1,000 gal/min pumping rate. After this time, the pressure in the main loop and plant container will be close to atmospheric and water can then be recirculated to the core by using the plant container drain pumps, through a cooler and back to the core. The duplicate boiler feed pumps and transfer pumps are fed by separate busbars.

Plant Container

All high pressure primary circuits are located inside the container and low pressure auxiliary circuits in the adjacent auxiliary building, a pressure reducing station being located in the container to reduce the pressure of the primary coolant passing to the purification loop.

The purpose of the plant container shell is to contain all fission products in the event of the maximum credible accident. Evolution of pressure and temperature versus time have been thoroughly investigated and determined, and it was found that, in the worst conditions, the pressure would always remain below the design figure of 45 p.s.i.g. and the temperature below 260°F. The conditions chosen as design criteria are the following:

worst loss of coolant accident, considered to be the simultaneous rupture of the 16-in. hot leg of the primary coolant system and the 10-in. main steam line, accompanied by complete melt-down of the core. The safety injection and the water spray are assumed to remain inoperative;

chemical reaction with water of 25% of the zirconium contained in the control rod extensions;

subsequent release in the container of all gaseous and volatile fission products accumulated in the core after one year of full power operation (although the core design lifetime is 7,000 hours only).

A special study was also performed concerning the possible ejection of the closure head or the failure of the bottom weld of the reactor vessel. Calculations indicate that the reactor vessel parts will remain confined inside the concrete reactor compartment.

To protect people living in the immediate vicinity of the plant, the steel shell is entirely lined internally with concrete for biological shielding in the very remote eventuality of this maximum accident. This shielding concrete serves also as a supporting means for the circular crane. This shielded design has been adopted to always permit access in the vicinity of the plant even after an accident. It should be noted that there are a canal, a conventional power station, and the other reactors, buildings and laboratories of the Mol site, in the immediate surroundings.

II—PLANT CONSTRUCTION

It was decided to build the BR-3 plant on a peninsula in one of the lagoons of Mol, 65 km north-east of Brussels. Work on the site was started in November, 1957, by the driving of sheet piles around the container enabling the pouring of a concrete mat during the winter 1957-1958, this being ready for the erection of the container at the end of March, 1958.

The container was leak tested in the beginning of March, 1959. During the period of erection the office building, the turbine hall and part of the auxiliary building were started. After the completion of the container leak test, the concrete foundation of the container and part of the concrete inside were poured to enable the erection of the plant container crane during the civil works contractor holidays, in August, 1959. This commenced a period of close integration between concrete pouring and erection, until the pouring of the concrete dome, which is just completed.

The pressure vessel and the steam generator were introduced in October, 1959; the piping work started in January, 1960, outside the container and in March inside the container. The main coolant pipes are welded and the primary loop has been closed, flushed and hydrotested.

The electrical cabling started in March, 1960, and tests began in June. The turbogenerator set and its auxiliaries are in place. Erection of the secondary piping work is under way.

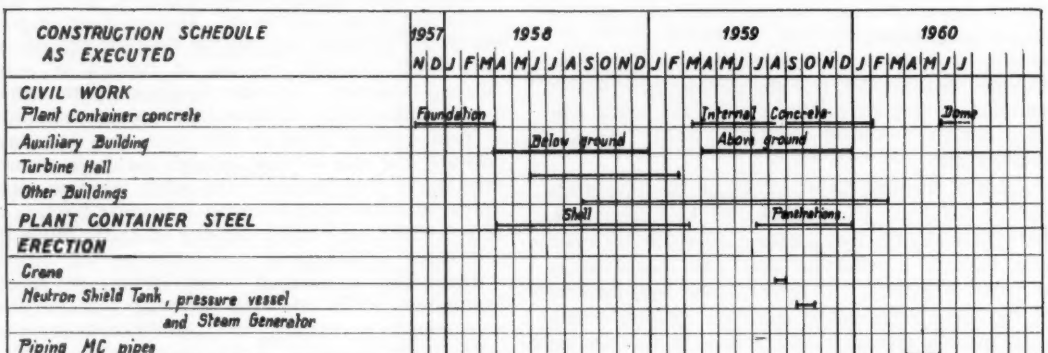


Fig. 2.—Construction schedule to the present time.

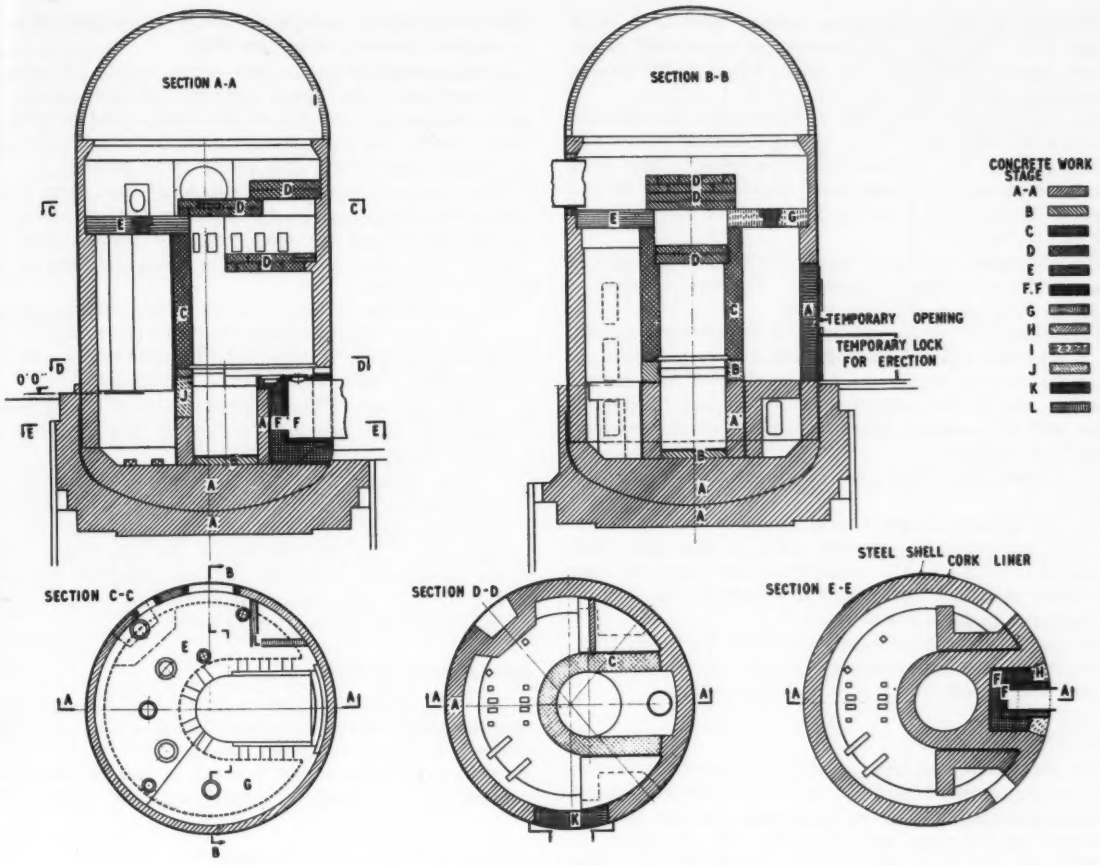


Fig. 3.—Key drawing showing placing of concrete.

The schedule for the future months covers the final closing-up of the neutron shield tank, after hydraulic testing of the primary loop, the hot-run test, the erection of the internals and the core, after which a period of pre-critical test will take place. It is now expected that criticality will take place before the end of this year. Fig. 2 shows, briefly, the erection schedule up to this date.

Design of the Foundation

The plant lies on hard sand. Piles were used only for the waste and ventilation building and for the stack where the hard sand was deeper, and the loads, due to shielding walls, more concentrated.

However, the various buildings had a different specific load on the ground, so that the foundations were separated, and joints provided between them. This has influenced the general design, especially because the water-table is very close to the ground surface (9 ft) and special tightness protection had to be provided around all buildings lower than that level (container and basement of the auxiliary building). Due to the possible differential settlements the pipe hangers had to be designed so as not to introduce stresses on the pipes, which are anchored at the container shell (auxiliary pipes) or near it (feed water and steam lines).

Plant Container Construction

The container was built as follows:

(a) Piles were driven down to level −55 ft to form a polygonal figure; the diameter of the inscriber circle is 70 ft.

(b) A concrete mat ranging from −37 ft to −30 ft 6 in. in the centre and −20 ft 8 in. on the sides was poured to act as platform for the erection of the container.

(c) during construction and test the shell was supported by 12 temporary steel columns, braced two by two. Both the internal and external surfaces were thus accessible for erection radiographs, leak test and occasional repairs at the outside.

(d) After testing, the concrete was poured below and on the side of the plant container up to ground level, alternately with the pouring of the bottom concrete inside the container to avoid forces on the steel and minimize the distortion. The temporary columns were afterwards cut out to avoid local stresses.

The shell has a central cylindrical section $1\frac{1}{4}$ in. thick with a hemi-ellipsoidal bottom $1\frac{1}{4}$ in. thick and a hemispherical dome $\frac{11}{16}$ in. thick. The metal chosen was Soudotenax 41 (C 0.18% max, Si 0.20% max, Mn 0.8-1%, S 0.04% max, P 0.03% max). The plates are welded together with Arcos Ductilend (for the first pass) and Navalend electrodes.

The penetrations of pipes are concentrated in four plates, and all electrical penetrations in one special plate. All penetrations needed reinforcement of the steel sheet thickness depending upon the size of the opening, the main ones being:

the main access lock opening, cylindrical, 10 ft 2 in.

diameter, is reinforced by an annular plate 2 in. thick and 2 ft 3 in. wide, surrounding the outer shell of the lock, and a second one 2 in. thick, with a width varying between 10 in. and 2 ft 9 in.;

the fuel transfer tank has a rectangular cross-section 4 ft 6 in. wide and 7 ft 6 in. high, terminated by two half circles. The reinforcement comprises a first plate 6 in. thick and 1 ft 7¾ in. wide, surrounded by a second plate 2¼ in. thick, having a width varying between 4 ft 2 in. and 6 ft;

the emergency personnel lock (circular), is included in a cylinder of 4 ft 6 in. diameter. The reinforcement is 2¾ in. thick on a 2-ft 3-in. width.

In addition to those openings, a temporary opening, 30 ft high and 15 ft 3 in. wide was cut at ground level after the test, to enable the construction of the internal concrete and the erection of interior equipment. The cut piece will be rewelded after completion of the erection inside the container.

Cable penetration tightness is ensured by two different means:

for all ordinary control and power cables, junction boxes are provided on both sides of the shell, with terminal blocks. All conductors are grouped into mineral insulated cables which penetrate the shell in bi-conical metal-to-metal seals;

the coaxial and triaxial cables are cut at the penetration; one end is fitted in a receptacle, screwed to the container shell, and the other in a male plug connector.

Plant Container Test

The plant container has to satisfy two basic conditions; resistance to internal pressure, without developing undue stresses, and tightness at the maximum credible accident pressure. In this case, the admissible leak was given as 0.1wt% of contained gas per day at 45 p.s.i.g. The following rigid controls include:

(1) Non-destructive testing during erection, including dye penetrant check, radiography and ultrasonic control of 100% of the welds.

(2) Control of the dimensions during erection.

(3) Control of the behaviour under pressure, with leak location detection by soap bubbles and observation of stresses by strain gauges. This check was made after the erection of the shell on its temporary supports, the whole of it being entirely accessible, and all openings being closed by temporary closure plates.

(4) Checking the tightness of the shell, after completion, with all locks, seals, and penetrations installed, with a measure of the leaks.

The test run after completion of the shell included also a leak measurement, in order to study the method to be used for the final test after completion of the plant.

The pressure was raised step by step. After a first step all welds were covered with a soap solution, and only few minor leaks were detected at pipe penetrations where any other control was impossible. The method showed a high sensitivity. After repair, a new soap test was made at all penetrations, and another leak was detected at the closure plate of the fuel transfer tank.

The leak test was performed by the use of a differential manometer, similar to that used in Vallecitos. Two compressors pumped air inside the container, the air being dried to avoid any possibility of condensation.

Precautions were taken during the test to protect the people and the shell. For the shell's sake care must be taken to avoid, by a too-sudden pressure release, a temperature drop which could produce a brittle fracture. Also the external temperature has to be watched to avoid a negative pressure inside the shell.

People involved in the test were, during all pressure rises, protected by heavy concrete shielding walls and an exclusion area of 400 m was maintained around the plant during the test. Access around the container was permitted, only after a 25% reduction in pressure.

The preparation of the tests took 20 days, their execution nine days, five for the pressure test, including the minor repairs and the soap test, four for the leak test. Fig. 4 shows the disposition of the equipment used for the leak measure test.

The conclusions of the tests are summarized hereunder:

The shell supported successfully the test pressure without any excessive stresses: local flexion stresses were low compared to the stresses induced by pressure.

The soap test is very sensitive, and should be run at relatively high pressure to enable the detection of minute leaks.

Great care is necessary in the installation of the strain gauges and the—necessarily long—cable runs.

The leakage rate test gave information on the accuracy of the instrumentation and the length of the test necessary to obtain the required precision; to reduce the error of the measurements below 30% the test should be run for at least 72 hours.

Special Erection Problems

As said previously a close integration of the civil works and the mechanical erection inside the container brought about a series of difficulties, which enforces our opinion that shielding walls should as much as possible be located outside, and not inside, the plant container shell. The

TABLE 1.

Co-relation of civil engineering work with plant erection

Civil work	Erection
A. Concrete mat and cylindrical wall close to the shell.	Crane.
A1. U wall around the reactor vessel and neutron shield tank.	Introduction of the fuel transfer tank. Steam generator temporary support. Neutron shield tank support frame. Lining seal ring.
B. Grouting of seal ring.	Neutron shield tank, pressure vessel, steam generator.
C. Walls of reactor pit.	Steel form for two thirds of operating floor, anchoring pieces.
D. Outside the container, pouring of concrete slabs needed to close the reactor pit during plant operation.	
E. Pouring of two thirds of the operating deck, and plugs.	Introduction of concrete slabs and large internals, on top of the two thirds of the operating deck.
F. Pouring of concrete around the stiffeners of the fuel transfer tank and between this concrete and the reactor pit walls.	Steel forms for remaining third of operating deck and anchorings.
G. Remaining third operating deck and plugs.	Lagging of reactor vessel. Final supports of steam generator main coolant pipes. Auxiliary pipes. Lining of refuelling canal.
H. Concrete behind expansion joint of lining.	Closure of reactor head. Closure of reactor pit with slabs.
I. Concrete dome.	Completion of neutron shield tank.
J. Concrete temporary openings for welding of the main coolant pipes on the reactor nozzles.	Closure of temporary openings of shell.
K. Closure of opening in shielding walls in front of temporary opening.	
L. Shielding wall pressure reducing station.	

small dimensions inside the container made the problem more stringent.

It is interesting to note that 11 different phases were encountered for the pouring of the concrete inside the shell, a mechanical erection phase taking place between each two successive phases (Table 1).

It must be kept in mind that the special cleanliness requirements for the primary cycle components erection made the integration of concrete pouring and erection work very difficult and necessarily induced time losses and repeated cleanings.

Cleanliness

Cleanliness rules were enforced during the erection of all the primary loop. This involved the erection, outside the plant buildings, of a piping shop, in which auxiliary pipe sub-assemblies were welded. After erection of the major equipment, measurements were taken and isometric drawings of the pipelines made. Pipes taken from the warehouses, were cut and bevelled in regular shops, and then cleaned by immersion in a hot solution of Oakite 33, rinsed with flushing demineralized water, and washed again in a hot bath of demineralized water. Their cleanliness was checked with acetone on a rag. They were afterwards introduced into the clean shops, where, after a cleanliness inspection, they were assembled into lengths limited by the introduction possibilities.

These shops were submitted to very close control and were built with air locks, filtered air supply, sealed windows, smooth surfaces, painted floor. The welders were equipped with white overalls, without buttons or pockets, white gloves, white caps and clean shoes. As far as possible, the same conditions were enforced inside the container and the auxiliary building basement, where all walls were painted before the job started.

After erection, a flushing operation with demineralized water was run in July before the hydro-test.

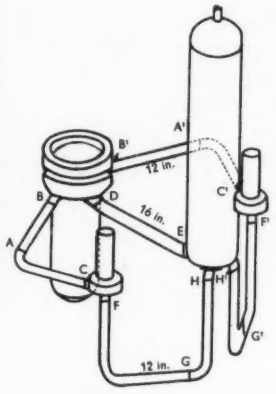


Fig. 5.—Key to welding order for main coolant loop.

Main Coolant Pipe Welding

The main coolant system consists of one hot leg, 16 in. o.d., 12.375 in. i.d., and of two cold legs, 12 in. o.d., 9.875 in. i.d. The general layout is shown in Fig. 5.

The 304 stainless-steel pipes are made out of forged billets, and forged elbows are used. The welding was made partially in manufacturers' shops in the U.S.A. and partially on the site (14 welds).

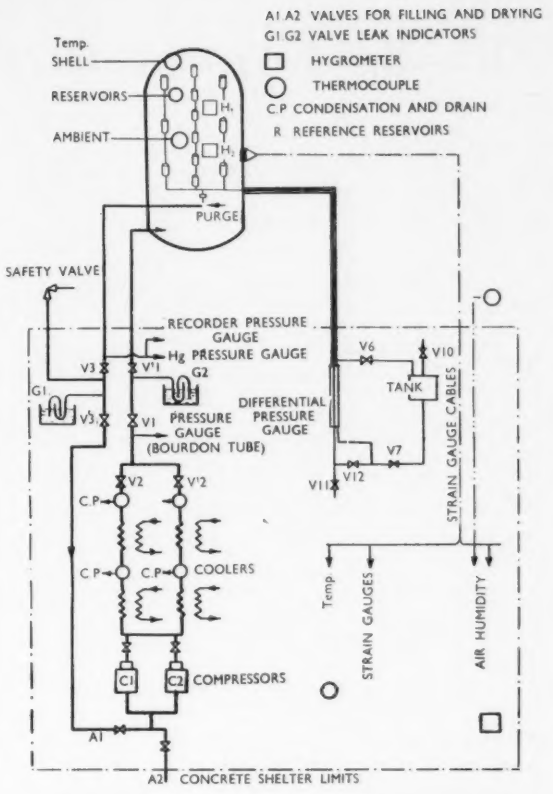


Fig. 4.—Diagram of set-up for pressure-testing container.

The welds A and A[1] were made in the clean shop built on the site between April 1 and 10 and the L-shaped pipes between reactor and main coolant pumps were then introduced in the container for welding to the reactor nozzles and pump outlets. During the welds a close control of the end movement allowed the possibility of correcting their displacements.

The welding in the container started on April 22 with the two 16-in. welds, D and E, which were finished on April 29.

As soon as the 16-in. welds were brought to $\frac{3}{8}$ in., the welds were started on the 12-in. lines, in B, C and B[1], C[1], and the movements of the main coolant pump volutes were closely checked. As soon as those four welds were performed, a measurement was made for adjustment of the L-shaped legs FG and F[1]G[1], which were sent into the pipe contractor shop for cutting to length and bevelling. These legs had been shipped with extra lengths for an adjustment. This was done between April 18 and 20 for the FG section, and between April 19 and 23 for the F[1]G[1]. Those sections were erected at the same time as the GH and G[1]H[1] sections, and to avoid trouble due to shrinkage, the welds FGH, and later F[1]G[1]H[1] were made simultaneously. All welds were completed on May 31 and all the radiographs accepted on June 10.

The root pass of the weldings was made with a consumable insert, melted by a tungsten arc under inert gas purge; the filling by electric arc with consumable electrodes, using two welders per joint. Imposed controls included a dye penetrant check after the root pass; dye penetrant check and radiograph after $\frac{3}{8}$ in.; dye penetrant check and radiograph after completion.

BR—3—Contractors

Architect Engineers

BUREAU D'ETUDES NUCLEAIRES (BEN), Brussels.
SOCIETE BELGE POUR L'INDUSTRIE NUCLEAIRE (BelgoNucleaire), Brussels.
SOCIETE DE TRACTION ET D'ELECTRICITE (TE), Brussels.

Main Supplier

WESTINGHOUSE ELECTRIC INTERNATIONAL COMPANY, New York, Gibbs and Hill (Architect Engineer for Westinghouse).

Continental Manufacturers and Suppliers

ACEC (Ateliers de Construction Electriques de Charleroi), Charleroi. Generators (main and auxiliary), cables.
ACECO (Association of Ateliers de Constructions Electriques de Charleroi, Charleroi and Cockerill-Ougree), Seraing. Erection of material of the primary system, connected instrumentation and cabling and piping inside plant container.
ANBUMA, Antwerp. Check valves (manufacturer, Biondi).
APPLICOM, Antwerp. Relays (manufacturer, English Electric).
ABR (Ateliers Belges Reunir), Division Tirlemont. Condenser and feed water heaters.
ATELIERS BOUCHOUT ET THIRION, Vilvorde. Steel frames and platforms, cable bridge.
ATELIERS D'ENSIVAL, Pepinster. Feed pump, auxiliary pumps.
ATELIER DE JAMBES, Jambes. Cable trays (supplier, Rieth, Germany).
ATELIERS GARDINAL, Jimaffes-lez-Mons. Cooling water pipes and auxiliary carbon steel pipes.
ATELIERS DE DELLE, Brussels. 3kV panel.
ATEA, Antwerp. Telephones.
AUXELTRA, Brussels. Lighting.
AUXELTRA-CFE, Brussels (Association between Auxeltra, Brussels and Chemins de fer et Eukepeiser, Brussels). Civil work.
AWANS-FRANSAIS, Awans-Bierset. Tanks.
BALTEAU, Liege. Relays, metering transformers.
BIONDI, Milan, Italy. Valves.
BROWN-BOVERI, Switzerland. Relays, synchronizing device.
BUREAU TECHNIQUE J. DEVIS, Brussels. Heating.
BETAFRA, Brussels. Water tanks.
BROOM AND WADE, High Wycombe, England. Compressors and air dryers.
CAMOY-VANDERSTEEN, Geut. Piping in basement.
CALTEX PETROLEUM CO. Oil.
CITAR, Brussels. Diaphragm valves.
COCKERILL-OUGREE, Seraing. Plant container shell.
DIAGRAMMES, Brussels. Instrumentation.
DONEKERS, Louvain. Valves.
D'HONDT, Brussels. Stainless steel lining, waste tanks.
DULLENS, Painting.
ELECTRO-APPAREILS, Brussels. Recorders.
ENI (Electro-tavale et Industrielle), Antwerp. Cabling.
EIB (Electricite Industrielle Belge), Veuies. 125 V panel.
EGEA, Brussels. SS tubes.
ENGLISH ELECTRIC, England. Relays.
FABRICOM, Brussels. Discharge tank, heat exchangers.
GARDY, Brussels. 380 V panels.
GENERAL ENGINEERING RESEARCH AND APPLICATION, Brussels. Air filters.
HOPKINSONS, England. Main steam valve.
HYDROBEL, Liege. Small pumps.
TRIS, Brussels. Painting.
ISOLEX, Brussels. Lagging.
JASFAR, Liege. Valves.
LAUFFER FRERES, Brussels. Heat exchangers.
LEFEVRE, Rausart. Fuel tanks.
MAGLINI, Bergamo, Italy. Motor control panels.
MERCANTILE MARINE ENGINEERING, Antwerp. S S lining.
NEU, Tournai. Ventilation.
REGULATION ET MESURE, Brussels. Instrumentation (manufacturer, Bristol).
ROGELEC, Geut. Electrical panels.
ROSENGARDE, Brussels. Cranes.
SCHINDLER, Brussels. Lift.
SEAPI, Vilvorde. Filters.
SEM, Geut. Motors, transformers.
SAUNDERS, England. Diaphragm valves.
SIEVAG, Brussels. L.P. valves.
SIKI, Brussels. Waste pumps.
SIEMENS, Brussels. Manual synchronizer, transformers.
SOBELCO, Brussels. Heating plant, chemical treatment.
SOBECONIUM, Brussels. Pipes.
SOCIETE A ARENDOUCK, Brussels. Polyethylene pipes.
SOVEHEAUX, Liege. Water degassifier.
SMULDERS, Liege. Blowdown tank.
STEGU, Brussels. Instrumentation.
TOLERIS, Geut. Tanks.
TUDOR, Florival. 125 V battery.
VAPEUR INNOVATIONS. Feedwater valves.
WANSON, Brussels. Lagging.
WALSCHAERTS, Brussels. Emergency Diesel.
WARMER, Brussels. Compressed cork.

U.S. Manufacturers and Suppliers

ALCO PRODUCTS, P.O. Box 1065, Schenectady, N.Y. Pressurizer.
ALLOY STEEL PRODUCTS CO., Pittsburgh, Pa. Demineralizers.
AUTOMATIC SWITCH CO., 50-56 Hanover Road, Florham Park, N.J. Switches.
BABCOCK AND WILCOX CO., Barberton, Ohio. Reactor vessel.
BAILEY METER CO., Cleveland, Ohio. Primary plant instrumentation.
BERGEN PIPE SUPPORT CO., 50 Church Street, New York, N.Y. Pipe hangers.
BRISTOL CO., P.O. Box 1790 NBG, Waterbury 20, Conn. Primary plant instruments.
BROOKS ROTAMETER, Box 432, Lansdale, Pa. Rotameters.
BUXTON MANUF. CO., Dover, N.J. Heat exchangers.
CANNON ELECTRIC CO., Salem, Mass. Triaxial connectors.
CHAMPION, Springfield, Ohio. Fuel Ass'y containers.
CHEMPUMPS, Phila., Pa. Surge tank drain pump.
COMMERCIAL FILTERS CORP., Melrose, Mass. Filters.
CONOFLOW CORP., Phila., Pa. Flow nozzle.
COPE, Collegeville, Pa. Cables.
COPES-VULCAN DIV. (BLAW KNOX CO.), Erie, Pa. Globe valves.
DANIEL ORIFICE, Houston, Texas. Flow orifice.
DARLING VALVE AND MFG. CO., Williamsport 6, Pa. Gate valves, pneumatic gear.
DRAVO, Marietta, Ohio. Primary piping.
EDWARD VALVES INC., Chicago, Ind. Valves.
EDWIN WIEGAND, Akron, Ohio. Saunders valves.
ELECTRO PRODUCTS LABS., Cleveland, Ohio. MG sets—Inverter—Diverter.
FAIRBANKS, MORSE AND CO., Chicago 5, Ill.
FARRIS ENGINEERING, Palisades Park, N.J. Safety and relief valves.
FISHER GOVERNOR, Box 307, Marshalltown, Iowa. Valves.
FULTON SYPHON, Knoxville, Tenn. Valves.
GENERAL CABLES.
GENERAL IONICS. Demineralizers.
GOULD PUMP CO., Seneca Falls, N.Y. Boric acid pump.
GRAVER TANK, Carasanqua, Pa. Personal air locks.
GREER HYDRAULIC, New York, N.Y. Accumulators.
GRINNEL CO., 260 W. Exchange Street, Providence 1, R.I. Saunders valves.
GRISCOM-RUSSELL, Massillon, Ohio. Coiled tube exchanger.
HAGAN CHEM. AND CONTROLS, Pittsburgh, Pa. N.S.T. cooling coil.
HAMMEL-DAHL/FOSTER ENG. DIV., Warwick, R.I. Valves.
HANCOCK, Watertown, Mass. Valves.
HARRIS PUMP AND SUPPLY CO., Pittsburgh, Pa. Pumps.
INDUSTRIAL INSTRUMENTS, Cedar Grove, N.J. Steam analyzer.
JOY MANUFACTURING CO., St. Louis, Mo. Heater connection.
KIELEY AND MUELLER, Middletown, N.Y.
KEROTEN, Pittsburgh, Pa. Gate valves.
LAWRENCE PUMPS. P.C. sump pumps.
LONERGAN, Philadelphia, Pa. Safety valves.
MANNING, MAXWELL AND MOORE, Tulsa, Oklahoma. Safety valves.
MICRO SWITCH, Freeford, Ill. Micro-switches.
MILTON ROY CO., Phila, Pa. Test pump.
MINNEAPOLIS-HONEYWELL, Minneapolis, Minn.
NASH ENGINEERING, South Norwalk, Conn. Gas compressor.
OAKITE PRODUCTS, New York 6. Cleaning products.
ON MARK COUPLINGS, Los Angeles, Calif. Quick disconnect couplings.
PACIFIC, Long Beach, Calif. Valves.
PANALARM, Skokie, Ill. Alarm annunciators.
PENN INSTRUMENTS, Burges-Manning Co. Flow nozzles.
PHILA-GEAR WORKS, Phila., Pa. Motor oper. valves.
PRECISION INSTRUMENT CO., Philadelphia, Pa. Manometers.
WM. POWELL, Cincinnati, Ohio, Gate valves.
RAMSEY PUMPS AND SUPPLY, Pittsburgh, Pa. Auxiliary pumps.
REPUBLIC MNFG. CO., Cleveland, Ohio. Three-way valves.
ROHM AND HAAS, Philadelphia 5, Pa. Resins.
SARGENT AND LUNDY, Chicago 3, Ill. Plant container design.
SAUNDERS. Valves.
SCHUTTE AND KOERTING, Philadelphia, Pa. Strainers.
SALES CORP. OF AMERICA, Dresher, Pa. Filters.
SOLA ELECTRIC, Chicago, Ill. Constant voltage transformer.
SOLAR AIRCRAFT, San Diego 12, Calif. Joints.
SPRAY ENGINEERING CO., Burlington, Mass. Pressure spray nozzle.
TARGET ROCK CO., Hempstead, N.Y. Fuel transfer device.
TEMPFLEX, Compton, Calif. Expansion joints.
UNION STEAM PUMP, Battle Creek, Mich. H.P. pumps.
U.S. GAUGE. Gauges.
VALVAIR, Akron, Ohio. Saunders valves.
WEINMAN PUMP CO.
WESTINGHOUSE, East Pittsburgh Div. PC and C: Nuclear Instrum. Rad. Monitoring—Switchgear and device: M.C. pump switchgear.
WESTINGHOUSE, Blairsville Div. Nuclear fuel.
WESTINGHOUSE, Cheswick Div. Main coolant pump—Control rod mechanism.
WESTINGHOUSE, Hillside Div. Main control centres.
WESTINGHOUSE, Newark Div. Meters.
WESTINGHOUSE, Philadelphia Div. Steam generator turbine.
WORTHINGTON, E. Orange, N.J. Drain collecting tank pump.

BR—3

3. Core Design and Testing

By JAMES A. KILPATRICK
(Atomic Power Department, Westinghouse Electric Corporation)

This article, the third in the series describing BR—3, deals with the development problems associated with the core, and gives an account of some of the metallurgical troubles met with on both fuel elements and control rods. It also describes the criticality tests carried out in the U.S.

AT the very outset of the BR-3 project, Westinghouse engineers and scientists were faced with the following major development problems:—

Suitable structural materials for core fabrication.

Materials and techniques for fuel element fabrication.

Materials and manufacturing techniques for control rods.

The necessary incidental inspection and testing procedures, including criticality experiments.

As a beginning, the rather limited field of existing power reactor types and associated technology in 1956 was evaluated in the interest of providing the purchaser with the most practical concept at the earliest possible date. It was soon apparent that the Belgian interests would best be served by building upon an existing and proven reactor concept which was operating with some measure of satisfaction and reliability. The Shippingport reactor, a "first" in the electric utility power reactor field, offered a ready foundation on which to erect the BR-3 philosophical edifice.

Shippingport utilized uranium oxide fuel, clad with zirconium; a combination which was troublesome and relatively expensive to fabricate, but which appeared serviceable, and designers of the original BR-3 core contemplated using a uranium-zirconium alloy plate fuel element containing highly enriched U^{235}. This concept was rejected when it was learned that regulations would not allow the export of uranium containing over 20 wt % of U^{235}. It was then decided that uranium oxide fuel clad with zirconium, similar to that of the blanket regions of the Shippingport core, would be adopted as the basis for the BR-3 core design.

Early Stages

The early stages of the Belgian reactor design also included a core consisting of a zirconium structure resembling an egg crate, into which zirconium rods were inserted. Nine control rods were provided in this concept, which also featured a system of nozzles that allowed the coolant to enter at the bottom of the reactor pressure vessel and leave through other nozzles at the top of the vessel sidewall. Again, this early concept specified fuel assemblies of welded construction, a design which was subsequently discarded in favour of a mechanical joint arrangement whereby the Zircaloy fuel rods would be fastened to the Zircaloy end plates by screws. This was a significant improvement, and resulted in substantial savings in welding equipment and labour costs. It also greatly reduced the number of fuel rods and fuel rod assemblies rejected due to weld failures or to damage during the welding operations. The change also permitted the elimination of several inspection steps and reduced the level of skill required to operate the incidental test apparatus which up to this time had involved highly skilled personnel.

At the same time, attention was being paid to control rod design, which was presenting its own set of problems. Although hafnium had demonstrated its excellence as a basic control rod material, its non-availability for commercial atomic power application precluded its incorporation in BR-3 designs. Haynes-25, as an alternative material, offered considerable promise in that it had good corrosion resistance and its strength and creep resistance at elevated temperatures was quite high.

The disadvantages of Haynes-25, however, appeared to outweigh its advantages as a BR-3 control rod base. It was a "grey" material, in that it lacked sufficient neutron absorptivity to provide satisfactory reactor control. It was also noted that it became highly radioactive through the formation of Co^{60}, and the slightest degree of corrosion could be objectionable. Another approach was needed if an entirely satisfactory control rod material was to be found.

This, then, was the state of the art when a halt was called to the BR-3 development while certain site arrangements were formulated by C.E.N.

A Fresh Start

When Westinghouse resumed design work on the BR-3 reactor core in 1957, several former problem areas had been resolved. Stainless steel was now coming to the fore as an economical material which offered good structural and fabrication qualities, leading to full length compartmentalized cladding for fuel pellet distribution. It was deemed necessary that the fuel cladding be "free standing," i.e., not collapse under operating pressures.

This free-standing factor had been obtainable with Zircaloy only by incorporating an extreme thickness in the clad, which would increase the cost. Further, Zircaloy employed an inert gas welding technique, adding significantly to core fabrication costs. Sizeable losses were incurred in the transition from zirconium sponge to ingot to tube at that stage of the art, although considerable improvements in the conversion technique have subsequently been developed. An example of the former degree of loss may be in order here.

On April 1, 1959, a start was made on melting 6,075 lb of blend Q 136 zirconium sponge. By April 11, eight ingots had been melted for a total as-cast weight of 5,437 lb, representing a casting loss of 11%. This was in addition to a 15.5% loss incurred in going from sponge to ingot. Yet this ill-starred, but representative, melt was destined for further reduction when an electrode became stuck and deposited a large amount of tungsten.

Manufacturing difficulties next beset the venture, with mere handfuls of acceptable tubing remaining after a rigid Westinghouse inspection had discarded the bulk of the material due to gouges, lack of uniformity in wall thickness, evidences of severe cold working, etc. Many of these

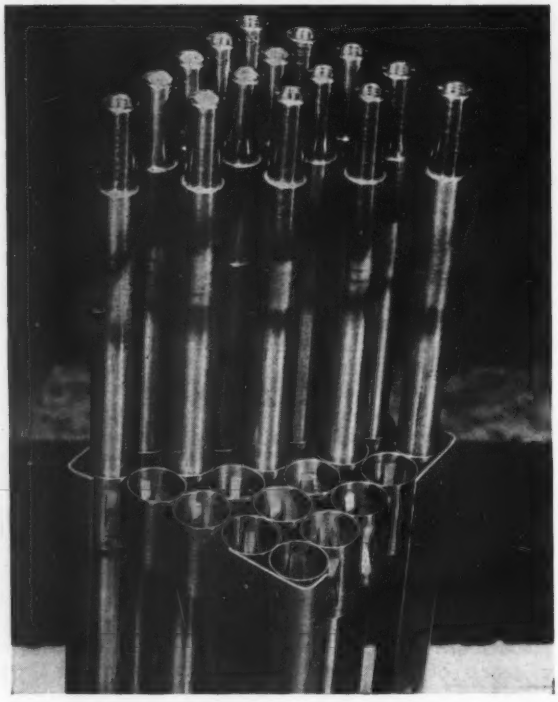
rejections arose from attempts to secure high production runs without allowing sufficient time for the intermediate annealing stages. If costs on BR-3 core fabrication were to be brought into line, a practical and economical substitute for Zircaloy was definitely needed.

Possibilities of Stainless Steel

The answer to this problem was finally obtained by the utilization of stainless steel. The major objections to implementing this solution lay in the gaps in stainless steel welding techniques, and the greater neutron capture ability of stainless steel. Since this latter factor was something that apparently had to be "lived with," Westinghouse metallurgists and welding engineers turned their attention to the problems of working and brazing stainless steel.

Independent and concurrent Westinghouse research and experimentation on the "Yankee" core, then being designed for the Yankee Atomic Electric Company nuclear plant at Rowe, Massachusetts, indicated that stainless steel could be worked and brazed to suit BR-3 fuel cladding requirements. This led to the development of the present BR-3 fuel rod arrangement whereby the pelletized uranium oxide—each pellet approximately the size of a lead pencil eraser—is loaded in full core length type 348 stainless steel rods. Each end of these rods is then hermetically sealed by welded-in stainless steel end plugs. This cladding also meets the BR-3 free-standing requirements and will not collapse on to the contained fuel pellets under operating conditions, ensuring a core with a very high degree of strength and integrity, since the individual fuel rods were now strong enough to serve as self-supporting structures. In order to capitalize upon this feature the BR-3 fuel rods are brazed together with spacing ferrules (Fig. 1). This type of construction provides excellent thermal, hydraulic, nuclear and mechanical characteristics—a nearly optimum realization of design objectives.

Fig. 1.—Assembling BR—3 fuel elements.



The brazing is conducted at approximately 1,875°F, which is well within the annealing temperature range for austenitic stainless steels. The efficacy of this technique has been confirmed through studies of various alloys deemed suitable for cladding. As a result of these studies and laboratory experiments, the properties of type 348 stainless steel tubing at reactor operating temperatures are, after brazing, definitely superior to those of other types. It was also found possible to correlate the clad collapsing data with the von Mises criterion utilizing the ensuing 0.2% yield strength of the material. The decision was, therefore, for stainless steel design, a choice which has also proven to be highly successful in other power reactors.

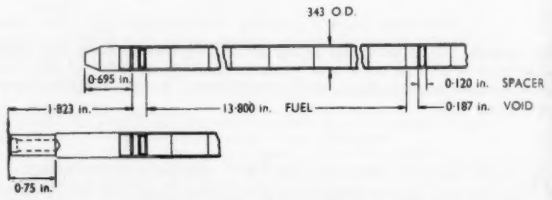


Fig. 2.—Details of BR—3 fuel rod.

CONTROL ROD DEVELOPMENTS

With the fuel clad problem solved satisfactorily, Westinghouse now turned to the BR-3 control rod design area. Here the problem was one of finding a suitable material, rather than arriving at a rod configuration. The cruciform control rod geometry had been well established at Westinghouse: the question was now "What suitable material is available?" Hafnium would have been eminently satisfactory due to its high degree of "blackness" to neutrons. Unfortunately, it was extremely scarce; consequently, three alternatives to hafnium were selected for consideration: cermets of homogeneously distributed boron carbide; combinations employing various rare earths; any remaining and hitherto untried neutron absorbers.

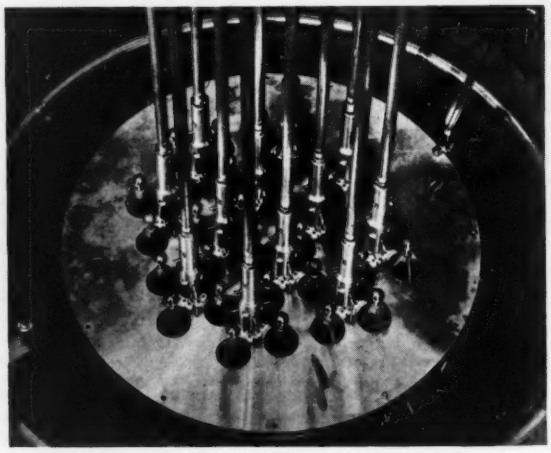


Fig. 3.—Top core plate with fuel elements and control rods installed.

Haynes-25, a cobalt-base alloy, received consideration due to its good corrosion resistance to demineralized, oxygenated water at 600°F and 2,000 p.s.i. Strength and

creep resistance qualities of Haynes-25 are also quite high, even at elevated temperatures. There was, however, a serious inherent disadvantage: a grey material, it did not possess enough neutron absorption cross section to ensure satisfactory BR-3 reactor control. This disadvantage was sufficient to turn attention to a silver-indium-cadmium combination as a likely solution.

The practicality of this Ag-In-Cd combination had already been pretty well developed. Since the BR-3 designers now had a proven technique in their possession, all research on alternative materials was halted and the search now turned towards finding suitable suppliers of this unconventional alloy. After a sufficient supply of

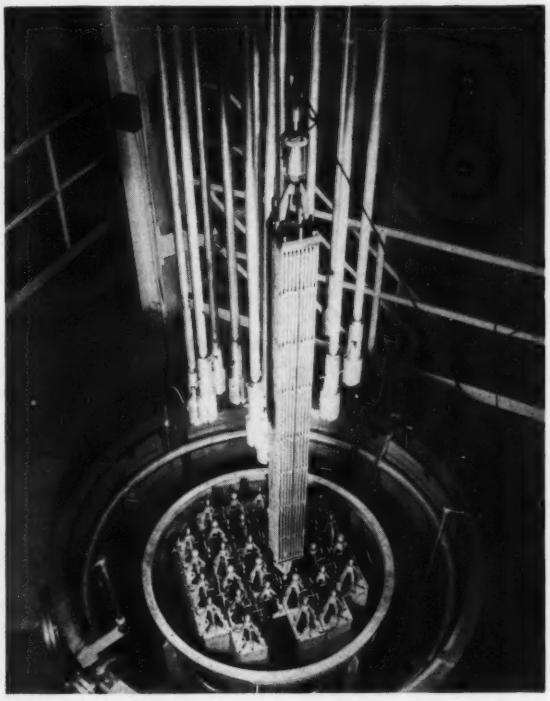


Fig. 4.—Placing a fuel assembly in the core during the criticality tests.

Ag-In-Cd had been assured, laboratory tests began in earnest. As usual, there were problems.

Corrosion Problems

Two major drawbacks to Ag-In-Cd soon developed. The alloy became severely corroded in an oxygen-containing fluid at elevated temperatures. Even more dismaying, an insidious corrosion penetration of the alloy developed as a straight-line function at elevated temperatures, even in the absence of oxygen. This showed up in cross-sectioning of the test samples.

It was not considered an advisable solution merely to add inhibitors to the coolant as these could give rise to adverse radiation conditions. "Coupons" of Ag-In-Cd were nickel-plated and heat treated for 1 hour at 550°C. The coupons were then subjected to laboratory tests wherein boric acid and oxygen combinations simulated actual reactor refuelling conditions. Again there were unmistakable evidences of galvanic corrosion. This problem was solved by heat treating the alloy for 4 hours at 600°C, instead of the previous 550°C at only 1 hour.

Fig. 5.—The equipment platform at the Westinghouse Reactor Evaluation Centre, at Waltz Mill, Pa.

The result was a bond with a much wider diffusion region which now extended to the surface, overcoming both the corrosion penetration and galvanic corrosion problems. This is the type of control rod technology which is incorporated in the Belgian reactor today.

Zircaloy, despite its severe fabrication limitations, finally found a "home" in the BR-3 through its use in control rod followers: an application where its low neutron absorption ability becomes an asset rather than another problem to harass the reactor designer.

CRITICAL EXPERIMENTS

The soundness of the preliminary design of the BR-3 power reactor has been borne out in the criticality experiments conducted by Westinghouse at their critical test facility. A brief description of this facility may be of interest (Fig. 5).

W.R.E.C.

The light-water critical test facility forms an integral part of the Westinghouse Reactor Evaluation Centre (WREC), located near Waltz Mill, Pa., approximately 30 miles south-east of Pittsburgh. The Westinghouse tract covers some 850 acres. The WREC critical experiments room (CRX room), a portion of which appears in Fig. 6, is constructed principally of poured concrete, and has 1,340 sq ft floor area with a 50 ft high ceiling. A five-ton travelling crane is hung from the roof beams. An adjacent control room, with a 4½ ft concrete barrier wall, contains the necessary nuclear instrumentation and a closed circuit TV monitor for controlling experiments.

The biological shield wall reduces radiation from the test core at 1 kW to below 3 mr/h in the control room. Water-filled shield doors cover personnel access doors in the CRX room while experiments are in progress. Electric immersion heaters are provided to raise the temperature

Fig. 6.—The control room at W.R.E.C.

of the water in both the reactor tank and dump tank up to 160°F for making temperature coefficient measurements.

Critical experiments on the BR-3 reactor core and control rods were conducted with a twofold purpose: (1) the evaluation of core reactivity and control rod worths as a check on the nuclear analysis, and on the validity of previous experiments combined with analysis, in determining loading requirements and control rod worths; and (2) the evaluation of overall core power distribution as a function of control rod location. Since location of the control rods exerts a significant influence upon power distribution, this latter factor received special attention during the experiments (Fig. 3). All of these tests and experiments were highly important since the state of the art does not permit precise analysis for predicting core performance.

Flux Measurements

In the course of these critical experiments, different control rod positions were achieved by adjusting the amount of soluble neutron absorber dissolved in the moderator. Power distributions were then inferred from the activation of copper wires inserted at various locations in the core lattice. A few asymmetric control rod distribution cases were examined in order to determine the effects of non-uniform control rod location on power distribution.

Comparison between calculations and actual experimental data proved quite favourable. For example, the calculated reactivity of the boronated cases proved to be within 1% of the experimental value in all but one instance, wherein the boron appeared to possess somewhat greater worth in actuality than was predicted in the calculations.

Valuable information resulted from neutron flux distribution experiments by the copper wire activation previously mentioned. Results indicated that the power distribution throughout life in the normally loaded core will fall well within the values used in the core thermal analysis.

Due to neutron flux non-uniformities in the core resulting from the presence of control rods and the fact that the fuel rods were fixed firmly in their fuel assemblies, no microscopic parameter measurements were performed (i.e., experiments leading to evaluation of the fast fission factor). Previous experiments leading to an evaluation of these parameters had already been conducted on fuel with similar physical characteristics, and measurements had been made on identical fuel rods.

The fuel assemblies were arranged in the critical facility core tank (Fig. 4) and were held in position by top and bottom core plates (Fig. 3). The basic measurements made on these various core arrangements were: reactivities, boron worth, partial water height, and worths of various control rods and temperature coefficients.

Measurements of the change in reactivity with water height were also made. The reactor was placed on a convenient period by alternately lowering the water level and withdrawing control rods until all rods cleared the water by at least 30 cm. Water was then bled out of the small boron circulating system into 2-litre flasks until the reactor levelled to the "just critical" condition. The total water so withdrawn was measured with an accuracy of 10 ml, and a separate measurement was made to obtain the factor for converting the volume change into a water height change.

The tests utilized banked control rod position, boron concentration, and axial water height in determining the values at which the various core geometries became critical. Variation of boron concentration was used in determining the worths of certain control rod combinations. In order to obtain banked rod worths as a function of position, boric acid solution was added and control rods withdrawn until the reactor was just critical at the various bank positions desired.

Temperature Coefficient Measurement

In the course of these experiments the temperature coefficient of the BR-3 core was measured. The reactor moderator water was heated by means of electric heaters to a temperature of over 75°C, and was then pumped into the reactor core. As the temperature of the reactor came down under natural cooling, precise thermocouple measurements were made in various parts of the core in order to establish a reactor cooling rate. At intervals, while the reactor was cooling, the core reactivity was determined from measurements of the reactor period. These observations at ambient temperature indicated the temperature coefficient to be negative, with a value of 5×10^{-4}/°C at 65°C, and 2×10^{-4}/°C at 30°C.

Upon completion of these successful experiments, the BR-3 core was readied for shipment to Belgium for subsequent installation and final operational checkout before joining the ranks of the European power producing reactors. This is scheduled for the near future, as soon as fuel arrangements are completed.

Direct Energy Conversion

WESTINGHOUSE recently successfully demonstrated in their Test Reactor at Waltz Mill, Pennsylvania, the operation of a dual generator comprising a thermionic element and a thermo-electric element.

The thermionic generator, which requires very high temperatures, was placed in the centre of the fuel element and the thermo-electric unit which operates successfully at intermediate temperatures surrounding it. The two in series produced roughly 1 watt of power.

These experiments form part of a broad programme aimed at examining the field of direct conversion, and exploiting the very high temperatures produced in the centre of many contemporary fuel elements.

Comments on the possible date for the use of such techniques for large-scale power generation indicate that research is in too early a stage for any real forecast to be made; there is no evidence to date which will allow one to predict confidently that such techniques will be economically applicable this century.

Uranium Carbide as Fuel

A Review of Current Knowledge

by A. STRASSER
(*Nuclear Development Corporation of America*)

ONE of the major obstacles to producing economical nuclear power is the lack of a completely satisfactory fuel which can operate at high power levels to long burn-ups. Fuels available today are limited by their mechanical instability. Metallic fuels change dimensions due to creep, to temperature and irradiation induced phase transformations and to the expansion of fission gases produced in the metal. Oxide fuels are stable dimensionally, but have low thermal conductivity; consequently, they are limited in power level unless the fuel core is allowed to melt. High temperatures and melting in turn release fission gases which have to be contained by the cladding. Oxide fuels have the additional disadvantage of having lower fuel density than metallic fuels. Fuel density becomes significant in natural or low enrichment reactors, as well as in reactors where compact size is required.

The fuel which appears to combine some of the advantages of metallic and oxide fuels is uranium carbide. Irradiation tests up to 14,000 MWd/t at fuel temperatures up to 880°C show dimensional stability and fission product retention ability comparable to UO_2. The thermal conductivity of UC is about 8-10 times that of UO_2, and two-thirds that of uranium metal. The density of UC is 24% higher than UO_2, 28% lower than uranium metal and 21% lower than U-10%Mo alloy. Thus, the carbide has a thermal conductivity and density between metal and oxide, with the apparent dimensional stability of the oxide. Every material has disadvantages, and uranium carbide is no exception. It oxidizes readily at room temperature, and is pyrophoric when in sufficiently small particle size. Nitrogen reacts to form the nitride and water reacts with and can dissolve uranium carbide even at low temperatures.

There are other, less significant, advantages and disadvantages of the material but it is the good thermal conductivity, stability during irradiation, high fuel density, and poor oxidation resistance that will determine its destiny.

Which reactors will benefit most from the good characteristics of carbide? Compatibility with coolant points to possible applications in sodium cooled, organic cooled, and helium cooled reactors. UC reacts with CO_2, but will probably be usable in CO_2 cooled reactors. Water cooled reactors will not use uranium carbide in the near future. However, there is a possibility that a stabilized, oxidation resistant carbide could be developed which retains its good thermal conductivity at the cost of some of its fuel density.

Sodium Cooled Reactors

The sodium cooled reactors gain the most immediate advantages from uranium carbide. All U.S. and U.K. sodium-cooled reactors are using or plan to use metallic fuels for their first core. At best, these fuels can achieve about 9,000 MWd/t at full power (~650°C maximum fuel temperature). Uranium carbide's minimum 14,000 MWd/t capability, and even higher potential, is a considerable economic incentive to its adoption for thermal and fast reactors. If the high melting point of carbide can be utilized, the power per fuel rod can be increased. As a consequence, fuel rod diameter is increased, and the number of fuel rods per core reduced. This can reduce core fabrication costs considerably.

The comparison of UC with other fuels in a thermal reactor is exemplified by a study NDA made for the U.S. AEC[74] on sodium cooled heavy water moderated reactors. The comparison is based on a 200 MWe, natural uranium reactor[64]. Structurally, it is a calandria with heavy water between the calandria tubes. The calandria tubes contain the fuel tubes which in turn contain the fuel element assemblies and the sodium coolant.

Substitution of UC for UO_2 in a reactor using Zircaloy-2 cladding and a Zircaloy-2 fuel tube (427°C coolant inlet and 550°C coolant outlet temperature) reduced fuel costs by 23% and energy cost by 4%. Substitution of UC for UO_2 in a reactor using niobium cladding and a niobium fuel tube (482°C coolant inlet and 621°C coolant outlet temperature) reduced fuel costs by 23% and energy cost by 14%. Substitution of UC, niobium cladding, stainless steel fuel tube (482°C coolant inlet and 621°C coolant outlet) for uranium metal, Zircaloy-2 clad, stainless steel fuel tube (427°C coolant inlet and 550°C coolant outlet) increased the fuel cost by 25%, but reduced the energy cost by 1%.

The above cost analyses were based on a most conservative evaluation of the data then available (February, 1959). The maximum UC temperature adopted was 950°C, the maximum UO_2 temperature 2,200°C, and the maximum uranium metal temperature 590°C. The potential maximum temperature for UC may be as high as 1,650°-2,200°C. If this were exploited, UC would appear even more favourable than UO_2 or uranium metal.

In the natural uranium reactors analysed, burn-up was reactivity limited, so that the high burn-up potential of ceramic fuels could not be utilized. Average assumed burn-up for UC was 6,850 MWd/t, and for UO_2, 5,500 MWd/t. Ceramic fuels (UO_2 and UC) appear economically more favourable than metallic uranium by a greater margin in enriched reactors, such as the sodium-graphite and fast breeder reactors. The first reactor to use uranium carbide will be the Hallam sodium cooled graphite moderated reactor which Atomics International has designed and is currently constructing. The reactor is scheduled for

Table 1—Comparison of Fuel Costs for Fast Breeder

Fuel	No. Rods per Assembly	Max. Fuel Temp. °C	Burn-up MWd/t	Pu Credit $/g	Fuel Cost* mill/kWh	Fuel Cost mill/kWh (Ref. 75)
U-10% Mo	144	613	11,000	30	8.8	9.2
				12	11.7	12.1
UC ..	36	1600	11,000	30	7.3	
				12	10.0	
			17,600	30	4.7	
				12	7.4	
			44,000	30	2.1	
				12	4.9	
PuC–UC	36	1600	17,600	30	6.4	
				12	5.9	
			44,000	30	2.9	
				12	3.4	
PuO_2–UO_2	225	2150	17,600	30	18.1	
				12	16.4	

* It is the comparison that is important rather than the absolute values.

Fig. 1.—Fuel cask developed by Atomics International for loading the 75MW Hallam sodium-graphite power reactor.

completion in 1961. Its first core of U-10%Mo rods will be replaced with arc-cast UC rods, starting in 1962. Burn-ups of 25,000 MWd/t are hoped for, at maximum fuel temperatures of 870°C. Subsequent advanced sodium-graphite reactor projects of Atomics International are also planning to use uranium carbide.

A cost analysis was made by NDA[66] to determine the effect of the substitution of UC for the Hallam U-10%Mo core. The maximum UC temperature assumed was 870°C compared to the maximum U-10%Mo temperature of 682°C. At the maximum burn-up feasible with U-10%Mo, about 8,800 MWd/t, the UC fuel cycle cost is 8% higher than the metal. But at a UC burn-up of 17,600 MWd/t, the UC fuel cycle cost is 18% lower than the metal. The cost reduction is based on UC performance that has been achieved today, rather than the full potential of UC.

The recent melt down accident of stainless steel clad uranium metal rods in SRE[72] points to another advantage of UC (and UO_2 as well), i.e., its compatibility with stainless steel cladding. Low melting eutectics are formed between stainless steels and uranium alloys.

An economic comparison of carbide fuels with other fuels in the Enrico Fermi Fast Breeder Reactor was made recently by NDA for the U.S. AEC[65]. The comparison was based on direct substitution of the fuel rod bundles in the design core, for the same core power, coolant flow area, external fuel sub-assembly dimensions and blanket fuel.

The striking reduction in fuel cycle cost is due to the higher burn-up possible with UC than with U-10%Mo, and the higher power per rod that may be possible with UC than with U-10% Mo and UO_2. The higher power results in larger and fewer fuel rods per assembly, whose total cost is considerably less. The lower thermal conductivity of oxides requires a large number of rods and pellets, raising the fabrication cost to a very high level. A more detailed description of this analysis, as well as an analysis of the effect of carbide fuels on the physics of fast reactors, is available in References 65, 77.

Organic Cooled Reactors

Organic cooled power reactor projects currently under development are planning to use UO_2 (Canadian G.E.) and U-3%Mo alloy (A.I.-Piqua). There is little reaction between UC and organic coolants as shown in preliminary corrosion tests. UC permits higher burn-up than U-3%Mo. The higher fuel density of UC compared to UO_2 permits lower enrichment. The good thermal conductivity of UC would not be as great an advantage here as in sodium cooled reactors, as the poor heat transfer coefficient of organic coolants is the limiting factor for the heat flux. Nevertheless, a cost saving would result from the substitution of larger diameter and fewer UC fuel rods for the smaller diameter more numerous UO_2 or metal rods.

Gas Cooled Reactors

To date at least, no plans have been announced for UC to be employed in CO_2 cooled reactors. With natural uranium fuels the lower density of UC compared with that of uranium metal probably puts a serious reactivity limitation on the reactor. Helium cooled, enriched fuel reactors are all considering the use of carbide fuels. The Oak Ridge gas cooled reactor will have a UO_2 first loading, but UC elements are being developed for subsequent loadings. UC-ThC fuel is being developed for both the General Atomics gas cooled reactor and the DRAGON successors. Aerojet is considering UC in graphite for a portable reactor. Advantages gained in gas cooled reactors are similar to the advantages in other reactors: higher burn-up than metal, higher temperature operation than metal, better fuel density and thermal conductivity than oxide, and in some cases, compatibility with graphite matrix and cladding.

PHYSICAL AND MECHANICAL PROPERTIES

A summary of the known properties of uranium and plutonium carbides is given in the attached data sheet. A certain amount of caution must be used in applying the properties to engineering problems because most of the UC produced in laboratories today is not pure or fully dense. The UC produced today can contain higher carbides of uranium such as U_2C_3 and UC_2. As UC is very reactive, it will also tend to pick up oxygen and nitrogen impurities during fabrication; the impurities may be present either in solid solution or as a second phase. Polycrystalline ceramics are nearly always porous to a degree; UC fabricated to date has varied from 80% to 100% of theoretical density. The properties of "UC" will be affected by purity, structure, and bulk density; therefore, one must evaluate the properties in light of the samples from which they were obtained. The purest and highest density UC has been made by arc melting uranium and graphite. Sufficient experience is not available to say whether high purity is required for good performance. Ceramics consisting of U-C-N-O may be good fuels.

Thermal conductivity is one of the most important properties to the fuel element designer. Thermal conductivity of ceramic fuels is also one of the most difficult properties to evaluate. Thermal conductivity in out-of-pile conditions will be at a maximum and probably cannot be matched in-pile. Ceramic fuels crack from the thermal stresses produced at any reasonable power level; the

Nuclear Engineering

DATA SHEET

No 15. Uranium Carbide

A summary of the world's literature on fuel carbide properties to supply necessary information to the programme and to point to areas where information is lacking.

The combination of PuC and UC has apparently not been studied to date. The two carbides will probably form solid solutions. The prediction can be made with reasonable assurance, based on the similarity of their crystal structures. The lattice parameter of UC is 4.955 Å while that of PuC is 4.910–4.97 Å; both carbides have a face centred cubic structure of the NaCl type.

1. *Physical and Mechanical Properties*

DENSITY (THEORETICAL AT 25° C)

	g/cc	Reference
UC	13.63	1
U_2C_3	12.88	2
UC_2	11.68	3
PuC	13.99±0.05	4
Pu_2C_3	12.70	5
PuC_2		

MELTING POINT

	°C	Reference
UC	2,500±25	6
	(Reported range 2,250–2,640)	7, 1, 8, 9, 10, 11
U_2C_3	Transforms to UC+UC_2 at 1,750–1,820	6, 12
UC_2	2,445	6
	(Reported range 2,350–2,475)	7, 9, 13, 14, 10, 15, 11
PuC	1,850	16
	Decomposes at > 1,400°C	17
	Decomposes at 1,654°C	63
Pu_2C_3	1,900	16
	Decomposes at 2,050°C	63
PuC_2	Decomposes at 2,250°C	63

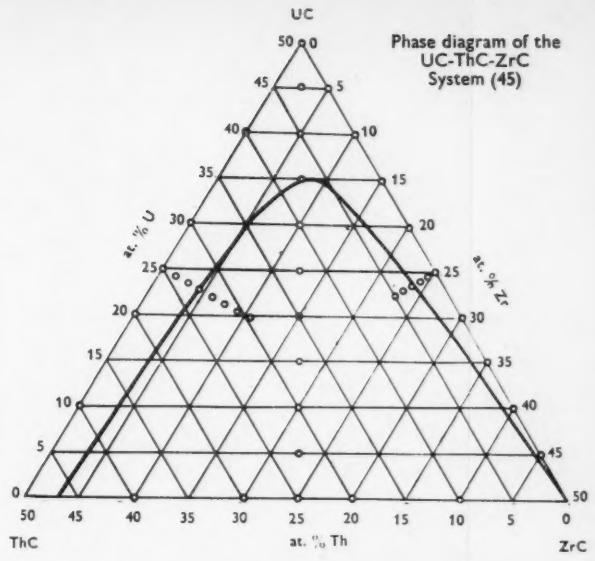
BOILING POINT

	°C	Reference
UC_2	4,100–4,370 at 760 mm Hg	9, 13, 14

CRYSTAL STRUCTURE

	Type	Lattice Parameters (Å at 25°C)	Reference
UC	Face centred cubic, NaCl type	a=4.955	6
		a=4.955	18*
		a=4.951±0.001	19
		a=4.951±0.004	20
U_2C_3	Body centred cubic	a_o=8.088±0.001	2, *21
		carbon-carbon bond distance=1.35±0.05	21
UC_2	Face centred tetragonal in pairs, CaC_2 type	a=3.524	3, 11
		c=5.999	
		a=3.54	18*
		c=5.99	
		a=3.517±0.001	19, 3
		c=5.987±0.001	
		carbon-carbon bond distance=1.34±0.02	21
PuC	Face centred cubic, NaCl type	a=4.910±0.005	22
		a=4.966±0.004	23
		a=4.97±0.001	23
Pu_2C_3	Body centred cubic, 8 molecules/unit cell	a=8.129±0.001	5*

* Spacings and intensities tabulated in reference.



Phase diagram of the UC-ThC-ZrC System (45)

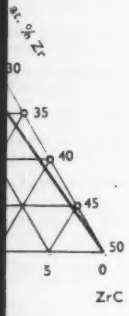
ELECTRICAL PROPERTIES : RESISTIVITY

	ohm-cm×10^{-6}	Reference
UC (arc welded)	41 (4.8 w/o C)	24
Other U–C alloys	40 (0.02 w/o C) 46 (2.4 w/o C) 45 (4.5 w/o C) 42–35 (5.0 w/o C) 45 (5.9 w/o C) 51 (6.8 w/o C) 57 (7.3 w/o C) 72 (8 w/o C) 83 (8.8 w/o C) 129 (9.3 w/o C)	24
UC	35–44 depending on impurities of Fe, Si, W, N, O, H_2	25
UC (10.2 g/cc)	10±4 (4.8 w/o C)	20
UC (as sintered)	100°C 60 500°C 230–270 (differed for heating and cooling) 700°C 180	46
(sintered and annealed 7 hr at 1,100°C)	100°C 25 500°C 60 850°C 100	
Electrochemical Potential		
UC	mV +320±50	20

THERMAL CONDUCTIVITY

	°C	cal/sec-cm-°C	Reference
UC (5.2 w/o C)	100	0.060	26
	150	0.058	
	200	0.056	
	250	0.055	
	300	0.054	
	350	0.053	
	400	0.053	
	450	0.053	
	500	0.054	
	550	0.055	
	600	0.057	
	650	0.058	
	700	0.060	
	735	0.061	
UC (4.8 w/o C, 10.2 g/cc)	60	0.080	20
	115	0.074	
	195	0.061	
	265	0.050	
UC (hot pressed, min. 98% of theoretical density)	119	0.046±0.003	46
	181	0.047±0.003	
	226	0.043±0.003	
	236	0.044±0.003	
UC_2	50	0.082 (density 10 g/cc)	9

ram of the
C-ZrC
m (45)



ITY

	Reference
	24
	24
	25
	20
	46
	20

	Reference
	26
	20
	46
	9

COEFFICIENT OF THERMAL EXPANSION

	°C	/°C×10⁶		Reference
UC	mean 20–950	11.4		
		Heating	Cooling	
Arc cast UC (5 w/o C)	20–100	9.5	10.3	26
	100–200	10.1	10.6	
	200–300	10.7	11.1	
	300–400	11.1	11.7	
	400–500	11.4	12.2	
	500–600	11.6	12.4	
	600–700	12.1	12.8	
	700–800	12.2	13.1	
	800–900	12.6	13.4	
	900–950	13.0	13.6	

	°C	/°C×10⁶				Reference
		14.2				
	mean 20–980	1st Heating	1st Cooling	2nd Heating	2nd Cooling	
Sintered UC	20–93	12.42	12.06	12.78	12.60	27
	20–205	12.60	12.60	12.78	12.78	
	20–316	12.96	12.96	13.14	12.96	
	20–427	13.14	13.14	13.68	13.50	
	20–538	13.68	13.50	13.87	13.87	
	20–649	13.68	13.68	14.22	14.04	
	20–760	13.68	13.87	14.22	14.22	
	20–871	13.68	14.22	14.4	14.4	
	20–982	13.32	14.58	14.4	14.58	

HEAT CAPACITY

	cal/g mole °K	Reference
UC	$C_p = 7.6 + 2.85 \times 10^{-3}$ T(298–2,400°K)	27
UC_2	$C_p = 8.92 + 3.95 \times 10^{-3}$ T(15 cal/g mole at 1,940°K)	20

MECHANICAL STRENGTH

		Reference
UC	Rupture strength of arc cast UC in compression (at 25°C): 54,500 p.s.i. with 0.17% total strain	26
	Bend strength (at 25°C): 30–40 kg/mm²	29
	Crushing strength (at 25°C): Parallel to direction of pressing 30±4 kg/mm²	20
	Perpendicular to direction of pressing 13±2 kg/mm²	20
UC alloys	Creep strength: 800 p.s.i. at 810°C up to 20 min: 0.05% C some improvement over U; 0.10% C considerable improvement over U; 2% C vast improvement, little deformation	32
	80 p.s.i. at 1,070–1,100°C up to 60 min: 2% C little deformation at 1,070°C; 3% C increasing twofold at 1,090°C	
	At 1,110°C creep rate is high, with 2% C having distinctly higher rate	
UC	Resistance to thermal cycling: 4.5 to 5 w/o C arc cast samples were cycled 100 times to 900° and 1,100°C (15 min cycles) with no evidence of fracturing	33, 34
	4.8 w/o C, 10.2 g/cc samples were cycled between 100 and 750°C 2,000 times without detectable changes. No changes took place on repeated quenching from 1,000°C to 25°C in vacuum	20
UC–U	UC–25% U was thermally cycled 1,000 times from 200 to 1,000°C without appreciable change in external appearance or microstructure	35
	3 w/o C cycled 1,000 times between 20 and 520°C was dimensionally stable	31
	Transverse breaking strength (at 25°C) 24,200 p.s.i. (4.8 w/o C) 15,300 p.s.i. (5.0 w/o C)	25
	The effect of Fe, Si, W, N, O, H_2 impurities were studied. Hydrogen and silicon are detrimental.	

MODULUS OF ELAST

	p.s.i. ×
UC (arc cast)	31.5 (at 2

MODULUS OF RUPT

	°C	ton/in.²
UC	25	5 (12% porosity)
	25	20–25 (UC+5/10
	100	10–15 (UC+5/10

HARDNESS

	Method of fabrication	Har
UC	Arc cast, 5.4 w/o C	600 VHN
	Arc cast, 5.2 w/o C, 1 hr at 1,000°C	563 VHN
	Above plus 1 hr at 1,500°C	763 VHN
	Above plus 5 min. at 1,650°C	776 VHN
	Sintered	700 VHN
	Sintered	750–800
	Sintered (10.84 g/cc)	700±150
	Sintered (10.2 g/cc)	550±50
UC_2	Arc cast	620 Kno load
	Sintered	500 Kno

2. *Chemical Reactivit*

$UO_2 + 4C \rightarrow UC_2 + 2C$

$-\Delta H = -188{,}540 - 0.8T + 4.05 \times 10^{-3} T^2 +$ $\times 10^5 T^{-1}$ cal/g at. of U

$-\Delta F = -188{,}540 + 1.842T \log T - 4.05 \times 1$ $T^2 + 2.34 \times 10^5 T^{-1} + 93.4T$ cal/g at. of

$\Delta S_{298} = 23.6$ ev

$\Delta F_0 = -202{,}500 - 16.17T \log T - 2.775 \times 1$ $+ 3.475 \times 10^5 T^{-1} + 156.75T$ K cal/g at

$\Delta F_{298} = -166.8$ K cal/g atom U

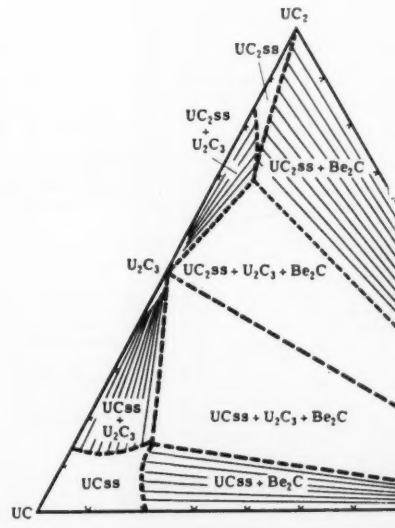
$\Delta S_{298} = 108$ ev

THERMODYNAMIC PROPERT

$\Delta F_{25} = -7.5$ K cal/g mole

$\Delta S_{298} = -8$ cal/deg.

$\Delta H_{298} = -76$ K cal



OF ELASTICITY

p.s.i. × 10⁶	Reference
31.5 (at 25°C)	26

OF RUPTURE

ton/in.²	Reference
% porosity)	29
(UC+5/10 w/o U)	
(UC+5/10 w/o U)	

RDNESS

	Hardness	Reference
	600 VHN	30
r	563 VHN	30
t	763 VHN	30
t	776 VHN	30
	700 VHN	31
	750–800 VHN	29
	700±150 VHN	20
	550±50 VHN	20
	620 Knoop, 100 g load	27
	500 Knoop	27

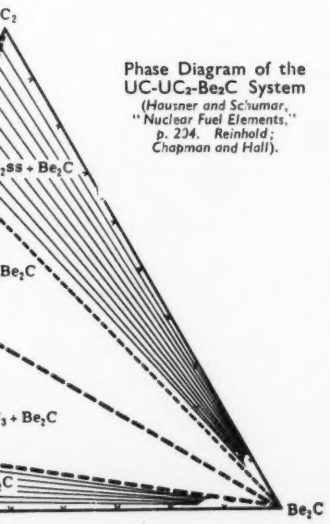
ical Reactivity

→UC₂+2CO

	Reference
$05\times10^{-3}\,T^2+4.68$	3
g $T-4.05\times10^{-3}$ T cal/g at. of U	3
$T-2.775\times10^{-3}\,T^2$ 5T K cal/g at. of U	3
U	3
	3

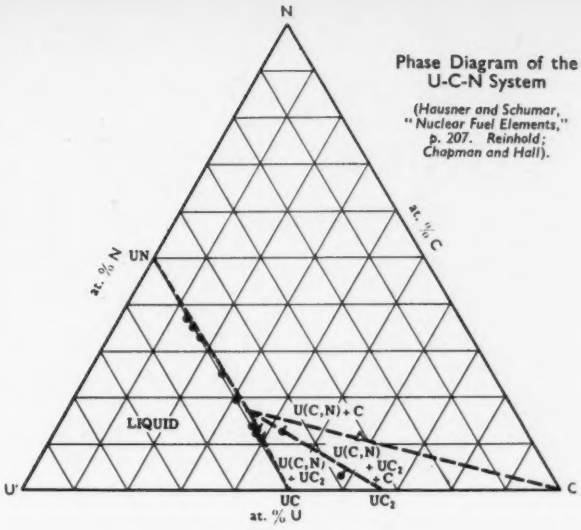
PROPERTIES OF U_2C_3

	Reference
	10
	10
	10



Phase Diagram of the UC-UC₂-Be₂C System

(Hausner and Schumar, "Nuclear Fuel Elements," p. 234. Reinhold; Chapman and Hall).



Phase Diagram of the U-C-N System

(Hausner and Schumar, "Nuclear Fuel Elements," p. 207. Reinhold; Chapman and Hall).

THERMODYNAMIC PROPERTIES OF UC

		Reference
ΔH_{298}	-20 ± 5.0 K cal/mole	27
	-20 ± 1 K cal/mole	6
	−25 K cal/mole	10
ΔH_{298}	−43 K cal	10
ΔS_{298}	−2 cal/deg	10
ΔF_{25}	−41 K cal/g mole	15
ΔF_T	$U(\alpha)+C^*\rightarrow UC(s)$ (298–935°K)	
	$-19{,}190-0.25T\log T+1.55\times10^{-3}T^2+0.70\times10^5\,T^{-1}+0.37T$	27
	$U(\beta)+C^*\rightarrow UC(s)$ (935–1,045°K)	
	$-17{,}070+15.39T\log T-2.46\times10^{-3}\,T^2+0.35\times10^5\,T^{-1}-44.68T$	27
	$U(\gamma)+C^*\rightarrow UC(s)$ (1,045–1,405°K)	
	$-19{,}240+13.13T\log T-2.46\times10^{-3}\,T^2+0.35\times10^5\,T^{-1}-35.78T$	27
	$U(l)+C^*\rightarrow UC(s)$ (1,405→above)	
	$-22{,}440+13.13T\log T-2.46\times10^{-3}\,T^2+0.35\times10^5\,T^{-1}-33.50T$	27
ΔF°_f	(cal/mole) for $U(\beta,\gamma,l)+C\rightarrow UC(s)$	
	1,000°K −18,010	27
	1,100°K −17,620	
	1,200°K −17,170	
	1,300°K −16,730	
	1,400°K −16,300	
	1,500°K −15,610	

* *Graphite*

THERMODYNAMIC PROPERTIES OF UC_2

	Reference
ΔH_{298} −36 K cal	10
ΔS_{298} −5 cal/deg	10
ΔF_{25} −38 K cal/g mole	15
$\Delta F=-36-5T$ can be used to obtain free energy of formation at high temperatures	10
$\Delta F_f^\circ=A+TB$	36
A B °K	
−42,200 3.7 298–1,400 } $UO_2+4C\rightarrow$	37
−27,000 −2.8 298 } UC_2+2CO	38

$U+2C\rightarrow UC_2$

	Reference
$-\Delta F_0=3.925+6.3T\log T-3.48\times10^{-3}\,T^{-2}+7.545\times10^4\,T^{-1}+19.85T$ cal/g atom of U	3
$-\Delta H_{298}=3.92$ K cal/g atom U	
$-\Delta F_{298}=9.83$ K cal/g atom U	
$\Delta S_{298}=19.8$ ev	
$U(\alpha)+2C^*\rightarrow UC_2(s)$(935–1,045°K)	
$\Delta F_T=-37.540+21.79T\log T-0.96\times10^{-3}\,T^2-2.10\times10^5\,T^{-1}-66.72\,T$	27
$U(\gamma)+2C^*\rightarrow UC_2(s)$(1,045–1,405°K)	
$\Delta F_T=-39.710+19.53T\log T-0.96\times10^{-3}\,T^2-2.10\times10^5\,T^{-1}-66.72T$	27
$U(l)=2C^*\rightarrow UC_2(s)$(1,405°K and above)	27
$\Delta F_T=-42{,}910+19.53T\log T-0.96\times10^{-3}\,T^2-2.10\times10^5\,T^{-1}-55.56T$	27

* *Graphite*

Nuclear Engineering
DATA SHEET
No. 15 Uranium Carbide

Reactions with Solids

U–C Phase Diagram

The U–C phase diagram has been determined.[7,12] The high uranium section of the phase diagram has been determined in some detail.[39] Three compounds exist: UC, U_2C_3, and UC_2.

U–C–N Phase Diagram

The U–C–N phase diagram has been studied at 1,800°C.[40] UC and UN form solid solutions. This has been further confirmed by study of the UC–UN system.[41]

UC–Al

UC and UC_2 dispersions in Al react at 600°C in 27 hours to form UAl_3 and CH_4.[62]

UC–Be

There is no reaction up to 600°C.[42] There is a reaction after 12 hr, 15 kg/mm², at 650°C.[20]

UC–Cr

No mutual solubility was found.[45]

UC–Mo

There is no reaction unless excess carbon is present.[6]

UC–Nb

Probably compatible at 500°C.[44]

UC–Ni

Two distinct diffusion zones form after 10 minutes at 1,000°C. One zone was identified as U_6Ni.[20]

UC–Re

A eutectic exists at 1,850°C. Re does not form a carbide and should not react with UC.[6]

UC–Si

USi_2 is formed around 1,000°C.

UC–Stainless Steel (Type 300)

No reaction was observed during thermal cycling tests up to 1,100°C, 13 hours.[43] Stainless steel was embrittled in a UC–NaK–SS compatibility test: at 600°C for 2 weeks; reasons were not established. UC is reported compatible up to 1,000°C; at 1,100°C there is 0.004 in. penetration.[44] UC appeared to react with stainless steel during the irradiation of UC-stainless steel fuel plates above 540°C but below 1,000°C.[24]

UC–Ta

There is no reaction at 1,800°C in 2 hours.[25]

UC–Ti

At 1,100°C there is 0.005 in. penetration in 6 days; at 1,200°C there is marked attack.[44]

UC–Zr

There is a reaction after 12 hr, 15 kg/mm², at 650°C.[20] There is a reaction at 1,000°C.[46]

UC–UC_2–Be_2C

The phase diagram at 1,700°C has been studied.[50] Partial solubilities exist between the beryllium and uranium carbides.

UC–CR_3C_2

X-ray studies show partial solubility. Beginning with 20 mole% Cr_3C_2 there is only a single ternary phase.[47]

UC–HfC

X-ray studies indicate a continuous series of solid solutions.[6]

UC–Mo_2C

Mo_2C is slightly soluble in UC; 5 and 10 mole% Mo_2C are heterogeneous.

UC–NbC

X-ray studies indicate a continuous series of solid solutions.[47] The melting point curve and lattice spacing of alloys were determined.[49]

UC–TaC

X-ray studies indicate a continuous series of solid solutions.[47] The melting point curve and lattice spacing of alloys were determined.[49]

UC–ThC

X-ray studies indicate a continuous series of solid solutions.[61] Ternaries with ZrC were studied and found to be solid solutions.[45]

UC–TiC

X-ray studies indicate a solubility of about 10 mole% of TiC. As TiC content is increased, an increasing amount of UC_2 was observed. The solution of TiC in UC is effected with a contraction of the crystalline lattice but the parameters of the mixed phase rich in UC do not decrease as much as the additive law would permit. The observations also not in a state of equilibrium.[47]

UC–VC

Partial solubility exists in th VC is slight; however, the sol X-rays showed a miscibility gap

UC–WC

Up to 10 mole % WC appea

UC–ZrC

X-ray studies indicate a contin The melting point curve an determined.[49]

Pu–C

The Pu–C phase diagram was of PuC, Pu_2, Pu_2C_3 and PuC_2 w of solubility for carbon. PuC_2

Reactions with Liquids

Water

Sintered compacts of UC and (1 atm. pressure) in less than 1 room temperature and rapidly air, a green hydroxide is prod product is greyish-black. The and ¼ liquid and solid hydrocarb and H_2 on the corrosion rate Fe and W appears to have an oxygen appear to have a bene with water vapour at dark red oxide. UC decomposed compl

PuC was not attacked by cold hot water and precipitated the were methane and hydrogen butanes, acetylene, and ethy hydrolysis in the atmosphere hydrolized by boiling water.

Acids

The reaction of UC, UC_2, F HNO_3, HCl, and H_2SO_4 produ ethane and other hydrocarbons slowly at room temperature, Dilute acids react more rapidly slow at room temperature but slightly with H_2SO_4, HNO_3 up 75°C; it did not react with HC between PuC and cold HNO_3 w containing some NaF, there w carbon was deposited.

Alkalis

UC_2 decomposed readily in a

NaK

Compatibility tests of UC wi showed no serious attack; so At 800°C UC was reported com

Na

UC has good stability in Na

Bi

Uranium carbide did not app 3-hour test.

Zn

UC is wetted by molten Zn.

Pb

UC is not wetted by molten

Sn

UC is not wetted by molten

Organic Coolants

UC did not appear to be att few days.[53] No corrosion was diphenyl, and terphenyls up to loss occurred on UC in glycer

Reaction with Gases

Air and its Components

UC and UC_2 react readily room temperature. The carbid ture if the surface area is sufficie a particle size of 40 μ or less.[32] about 400°C and burns to U_3O_8 air U_2C_3 was found to have dis taining material with a metallic as it was heated to 300°C in air

rvations also indicate that the specimens were quilibrium.[47]

exists in the system. The solubility of UC in ver, the solubility of VC in UC is significant. iscibility gap.[47]

% WC appears to be soluble in UC.[47]

cate a continuous series of solid solutions.[47,48,45] t curve and lattice spacing of alloys were

diagram was studied recently.[63] The existence and PuC_2 were confirmed. PuC shows a range bon. PuC_2 is stable above 1,750°C only.

ls

s of UC and UC_2 disintegrated in boiling water less than 1 hour.[27] UC_2 decomposes slowly at and rapidly when heated.[3] In the absence of xide is produced. In the presence of air the black. The carbon is converted to ½ gaseous id hydrocarbons. The effect of Fe, Si, W, N, O, rosion rate of UC in 60°C water was studied. to have an adverse effect while hydrogen and have a beneficial effect.[24] The carbide reacted at dark red heat with ignition to form a black posed completely in moist air within a week.

cked by cold water but it effervesced steadily in cipitated the hydroxide.[16] The gases produced hydrogen with smaller quantities of ethane, , and ethylene. Pu_2C_3 was less stable to atmosphere than PuC, but it was less easily ng water.

UC, UC_2, PuC and Pu_2C_3 with acids such as H_2SO_4 produced hydrogen, acetylene, ethylene, ydrocarbons.[9,3] Concentrated acids react only emperature, and more rapidly when heated. more rapidly. Reaction of UC with H_3PO_4 was erature but rapid when heated.[3] U_2C_3 reacted , HNO_3 up to 170°C, vigorously with HCl at eact with $HC_2H_3O_2$ up to 170°C.[2] The reaction old HNO_3 was slight; when heated with HNO_3 laF, there was a steady evolution of gas, and ed.

readily in alkalis.[9]

ts of UC with NaK up to 700°C and 8 weeks attack; some weight loss was observed.[51,52] eported compatible with NaK for one month.[44]

bility in Na up to about 500°C.[42]

did not appear to react with Bi at 600°C in a

molten Zn.[20]

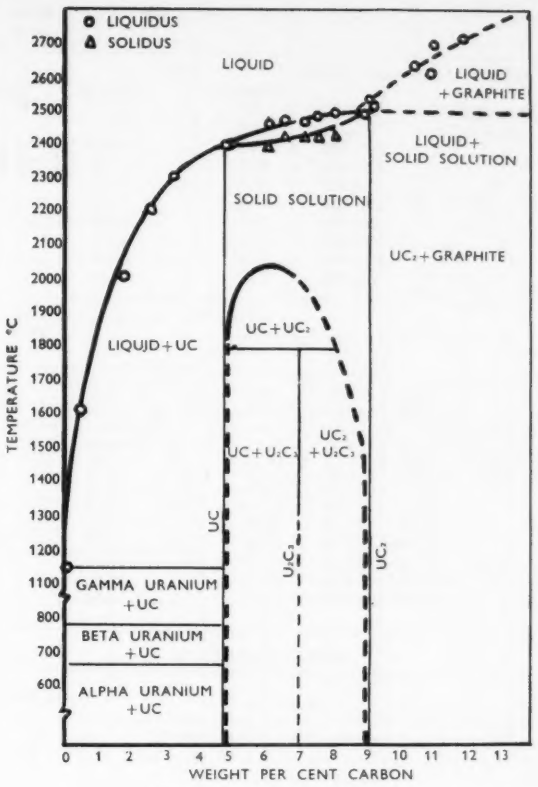
d by molten Pb.[20]

d by molten Sn.[20]

ar to be attacked in Santowax R at 400°C for a rrosion was detected on UC after 5 hours in henyls up to 350°C.[20] A 50 mg/cm²-hr weight UC in glycerine at 100°C.[20]

onents

act readily with oxygen and water vapour at The carbides are pyrophoric at room tempera- rea is sufficiently large; according to one source μ or less.[32] Dense UC_2 ignites in air or O_2 at rns to U_3O_8 and CO_2. After 5½ hours in 600°C to have disintegrated into granules still con- h a metallic appearance. PuC oxidized slowly 300°C in air.



The Uranium-Carbon System

Reaction of UC_2 with O_2, N_2, and water vapour has been studied.[27] The reactions follow the general equation $W=Kt^n$, where W=weight gain, K=rate constant, t=time, n=1 for the linear law and 0.5 for the parabolic law. The reactivity of UC_2 with water vapour followed the linear law.

Reactivity of UC_2 with oxygen followed the parabolic rate to 250°C. At 300°C oxidation proceeded anisothermally, and the temperature of the specimen rose to 1,000°C in less than one minute. Preliminary results on the reaction of UC with O_2 show that a parabolic rate is followed at somewhat more rapid rate than UC_2. PuC burned brightly in oxygen at 400°C.

Reactivity of UC_2 with nitrogen followed the parabolic rate to 700°C. After 12 hours at 1,100°C the carbide was completely converted to nitride.

F_2

No reaction occurred between UC_2 and F_2 at room temperature but slight heating resulted in an explosive reaction.[3]

Cl_2

At 350°C, UC_2 and Cl_2 reacted to form a volatile chloride. At 600°C UO_2+UC_2 reacted with Cl_2 to form UCl_4 leaving a large residue. At 800 and 1,000°C higher uranium chlorides were produced.[3]

Br_2

A reaction occurred between UC_2 and Br_2 above 300°C. UBr_4 was formed at 900°C.[3]

I_2

U_2C_3 reacted with I_2 at 600°C to give UI_4. I_2 vapour at a partial pressure of 100 mm passed over UC_2 at 500°C forms UI_4.[3]

NH_3

At red heat UC_2 decomposition takes place.[3]

H_2S

UC_2 ignited at 600°C in H_2S, and formed a sulphide.[3]

CO_2

UC oxidizes rapidly in CO_2 at 500°C; the rate is invariant to 830°C.[42] U–UC is analogous to U, but UC appears better than U. A UC specimen oxidized at "a rate of 0.6%" in 6 hr at 500°C, whereas U metal oxidized at "a rate of 6%."[31]

H_2

UC is compatible with hydrogen to high temperatures if no second phases are present.[44]

This summary is taken from NDA Report No. 2140–2 "Carbide Fuel Development" sponsored under AEC Contract AT(30–1)–2303, Project IV. The assistance of Mrs. G. Britto and Mr. R. Somasundaram in compiling the summary is acknowledged by the author.

1. R. Keiffe Behaviour (Nov., 19
2. M. W. N carbide,"
3. Report o (Sep. 15,
4. G. T. S Co., Inc.,
5. W. H. Z Acta Crys
6. M. Bown (August,
7. M. W. M
8. K. White Reports C
9. J. Baker,
10. Leo Brew "The Th Uranium
11. E. Eprem TID-7546,
12. F. A. Ro Alloys,"
13. M. P. A (Mar. 10,
14. T. A. Bu CC-164 (
15. W. R. M Elements (Mar. 20,
16. J. L. D Welch, " Part VII
17. J. Lemon (Aug., 19
18. L. M. Li Structures 1948).
19. R. E. Ru "Structur Soc., 70 :
20. A. Boetti carbide," Uses of
21. A. E. Au to Civilia
22. W. H. Z Cryst. 2 :
23. A. A. Bo in Conne Second U Atomic E
24. Progress
25. Progress BMI-1346
26. A. C. Sec carbide C
27. A. B. T Uranium
28. L. Brewer
29. E. Barne Uranium and Fuels Inc. (1956
30. C. A. Se NAA-SR-
31. J. Dubuis metric M Internatio A/Conf.
32. E. Barnes U-UC Ce
33. A. Secres Monocarb 1958, p.
34. A. C. Sec Monocarb 1958, p.
35. G. A. Me Conferenc (Sep. 10,
36. R. J. Ac Properties Conferenc (June, 19
37. O. Kuba John Wil
38. O. H. Ke

Uranium Carbide—References

1. R. Keiffer *et al.*, "The Preparation of Uranium Monocarbide and Its Behaviour Compared with Other High Melting Carbides," IGRL-T/C-52 (Nov., 1957).
2. M. W. Mallet, A. F. Gerds, and D. A. Vaughan, "Uranium Sesquicarbide," AECD-3060 (Jan. 31, 1950).
3. Report on the Carbides of Uranium: UC, UC_2, and U_2C_3, NEPA-273 (Sep. 15, 1947).
4. G. T. Seaborg, "The Transuranium Elements," McGraw-Hill Book Co., Inc., New York (1949).
5. W. H. Zachariasen, "The Crystal Structure of Plutonium Sesquicarbide," Acta Cryst., 5 : 17 (1952).
6. M. Bowman, Los Alamos Scientific Laboratory, Personal Communication (August, 1959).
7. M. W. Mallet, A. F Gerds *et al.*, *J. Electrochem. Soc.*, 99 : 197 (1952).
8. K. Whitehead, L. D. Brownlee and R. Raine, Metropolitan-Vickers, Res. Reports C-164, C-892, C-893.
9. J. Baker, "Uranium Carbide," NEPA-138 (Dec. 31, 1946).
10. Leo Brewer, LeRoy A. Bromley, Paul W. Gilles, and Norman L. Lofgren, "The Thermodynamic Properties and Equilibria at High Temperatures of Uranium Halides, Oxides, Nitrides and Carbides," BC-82 (Sep. 20, 1945).
11. E. Epremian, "Uranium Compounds for New High Temperature Fuels," TID-7546, Book 2 (Mar., 1958).
12. F. A. Rough and A. A. Bauer, "Constitution of Uranium and Thorium Alloys," BMI-1300 (June 2, 1958).
13. M. P. Ames Laboratory Reports CT-686 (May 22, 1943); CN-1495 (Mar. 10, 1944) and CC-1514 (Mar., 1944).
14. T. A. Butler, R. Fischer and A. S. Newton, M. P. Ames Laboratory CC-164 (May 14, 1943).
15. W. R. Martini, "A Compilation of the Vapor Pressure Data for the Elements from Br to U and their Oxides and Carbides," NAA-SR-215 (Mar. 20, 1953).
16. J. L. Drummond, B. J. McDonald, Heather M. Ockenden, and G. A. Welch, "The Preparation and Properties of Some Plutonium Compounds, Part VII Plutonium Carbides," *J. Chem. Soc.*, p. 4785 (Dec., 1957).
17. J. Lemons, Los Alamos Scientific Laboratory, Personal Communication (Aug., 1958).
18. L. M. Litz, A. B. Garrett, and Frank C. Croxton, "Preparation and Structures of Carbides of Uranium," *J. Am. Chem. Soc.*, 70 : 1718 (May, 1948).
19. R. E. Rundle, N. C. Baenziger, A. S. Wilson, and R. A. McDonald, "Structure of Carbides, Nitrides and Oxides of Uranium," *J. Am. Chem. Soc.*, 70 : 99 (1948).
20. A. Boettcher and G. Schneider, "Some Properties of Uranium Monocarbide," Second United Nations International Conference on the Peaceful Uses of Atomic Energy, A/Conf. 15/P/964.
21. A. E. Austin and C. M. Schwartz, "Structure of UC_2," Progress Relating to Civilian Applications During June, 1958, p. 40, BMI-1273 (July 1, 1958).
22. W. H. Zachariasen, "The Crystal Structure of PuN and PuC," Acta Cryst. 2 : 388 (1949). (Also ANL-4070, Oct. 14, 1947.)
23. A. A. Bochvar *et al.*, "Interaction Between Plutonium and Other Metals in Connection with Their Arrangement in Mendeleev's Periodic Table," Second United Nations International Conference on the Peaceful Uses of Atomic Energy, A/Conf. 15/P/2197 (July, 1958).
24. Progress Relating to Civilian Applications During June, 1959, BMI-1357.
25. Progress Relating to Civilian Applications During May, 1959, p. 51, BMI-1346 (June 1, 1959).
26. A. C. Secrest Jr., *et al.*, "Preparation and Properties of Uranium Monocarbide Castings," BMI-1309 (Jan. 2, 1959).
27. A. B. Tripler, Jr., *et. al.*, "Further Studies of Sintered Refractory Uranium Compounds," BMI-1313 (Jan. 27, 1959).
28. L. Brewer, M. P. Berkeley CC-672 (May 15, 1943).
29. E. Barnes *et al.*, "The Preparation, Fabrication and Properties of Uranium Carbide and Uranium-Uranium Carbide Cermets," *Metallurgy and Fuels*, Vol. V, Progress in Nuclear Energy, McGraw-Hill Book Co., Inc. (1956).
30. C. A. Smith and F. Rough, "Properties of Uranium Monocarbide," NAA-SR-3625 (June 1, 1959).
31. J. Dubuisson *et al.*, "The Preparation of U-UC Cermets and Stoichiometric Monocarbide by Sintering Under Stress," Second United Nations International Conference on the Peaceful Uses of Atomic Energy, A/Conf. 15/P/1162.
32. E. Barnes *et al.*, "The Preparation, Fabrication and Properties of UC and U-UC Cermets," AERE-M/R-1958.
33. A. Secrest *et al.*, "Casting Techniques for the Preparation of Uranium Monocarbide," Progress Relating to Civilian Applications During March, 1958, p. 69, BMI-1259 (Apr. 1, 1958).
34. A. C. Secrest *et al.*, "Casting Techniques for the Preparation of Uranium Monocarbide," Progress Relating to Civilian Applications During June, 1958, p. 45, BMI-1273 (July 1, 1958).
35. G. A. Meyerson, "Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy," Vol. 6, p. 564 (Sep. 10, 1958).
36. R. J. Ackermann and R. J. Thorn, "High Temperature Thermodynamic Properties of Reactor Materials," Second United Nations International Conference on the Peaceful Uses of Atomic Energy, A/Conf. 15/P/715 (June, 1958).
37. O. Kubachewski and E. L. Evans, "Metallurgical Thermochemistry," John Wiley and Sons, Inc., New York (1958).
38. O. H. Krikorian, "High Temperature Studies," UCRL-2888 (1955).
39. B. Blumenthal, "Constitution of Low Carbon U-C Alloys," ANL-5958 (Feb. 2, 1959).
40. A. Austin and G. Gerds, "The Uranium-Nitrogen-Carbon System," BMI-1272 (June 23, 1958).
41. R. A. J. Sambell and J. Williams, "The Uranium Monocarbide/Uranium Mononitride System," AERE-M/R-2654 (Sep., 1958).
42. P. Murray and J. Williams, "Ceramic and Cermet Fuels," Second United Nations International Conference on the Peaceful Uses of Atomic Energy, A/Conf. 15/P/318 (July, 1958).
43. A. C. Secrest, E. L. Foster, and R. F. Dickerson, "Casting Techniques for the Preparation of Uranium Monocarbide," Progress Relating to Civilian Applications During July, 1958, p. 43, BMI-1280 (Aug. 1, 1958).
44. R. W. Nichols, "Ceramic Fuels—Properties and Technology," *Nuclear Engineering* (Aug., 1958).
45. O. S. Ivanov and T. A. Badajeva, "Phase Diagrams of Certain Ternary Systems of Uranium and Thorium," Second United Nations International Conference on the Peaceful Uses of Atomic Energy, A/Conf. 15/P/2043 (July, 1958).
46. A. Accary, R. Caillat, "Development of Ceramic Fuel Elements in France," from the book by H. Hausner and J. Schumar, "Nuclear Fuel Elements," Rheinhold Publishing Corp., New York (1959).
47. H. Nowotny *et al.*, "The Preparation of UC and its Reactions with Carbides of the Refractory Transition Metals," *R. de Metallurgie* 55 : 453 (1958), AEC-TR-3415 (May, 1958).
48. W. Witteman, J. Leitnaker and M. Bowman, "The Solid Solubility of Uranium Monocarbide and Zirconium Carbide," LA-2159 (Apr., 1958).
49. L. D. Brownlee, "The Pseudo-Binary Systems of UC with ZrC, TaC, and NbC," *J. of the Inst. of Metals*, 87 : 58 (Oct., 1958).
50. M. Burdick *et al.*, "An X-Ray Study of the System $UC-UC_2-Be_2C$," *J. of Res. of the NBS*, 54 : 4 (Apr., 1955).
51. R. B. Price *et al.*, "Irradiation-Capsule Design for Uranium Monocarbide," Progress Relating to Civilian Applications During March, 1958, p. 70, BMI-1259 (Apr. 1, 1958).
52. R. B. Price and W. H. Goldthwaite, "Irradiation of Uranium Monocarbide," Progress Relating to Civilian Applications During November, 1958, p. 45, BMI-1304 (Dec. 1, 1958).
53. H. Pearlman, A. I., Personal Communication (Aug., 1959).
54. S. Alfant, G. Lamale, A. W. Hare, and F. A. Rough, "Post-irradiation Examination of Uranium Monocarbide," Progress Relating to Civilian Applications During November, 1958, p. 46, BMI-1304 (Dec. 1, 1958).
55. R. Lieberman *et al.*, "Fission-Product Release from Irradiated Uranium Monocarbide," Progress Report Relating to Civilian Applications During August, 1958, p. 38, BMI-1286 (Sep. 1, 1958).
56. Progress Relating to Civilian Applications During March, 1959, p. 73, BMI-1330.
57. F. A. Rough, "Evaluation of Uranium Monocarbide as a Reactor Fuel," Progress Relating to Civilian Applications During May, 1958, p. 63, BMI-1267 (June 1, 1958).
58. A. B. Tripler, Jr., M. J. Snyder, and W. H. Duckworth, "Preparation, Fabrication and Physical Properties of Uranium Compounds," Progress Report Relating to Civilian Applications During September, 1957, p. 43, BMI-1226 (Oct. 1, 1958).
59. J. B. Melehan *et al.*, "Literature Survey for the Appraisal of UC as a Possible Nuclear Fuel," Progress Report Relating to Civilian Applications During August, 1958, p. 14, BMI-1286 (Sep. 1, 1958).
60. F. Rough, Private Communication (Aug., 1959).
61. H. Nowotny *et al.*, "Zur Kenntnis des Teilsystems UC-ThC," Planseeberichte fuer Pulvermetallurgie, 5 : 102 (1957).
62. W. Thurber, R. Beaver, "Dispersion of Uranium Carbides in Aluminium Plate-Type Research Reactor Fuel Elements," ORNL-2618 (Nov., 1959).
63. R. Mulford, F. Ellinger, G. Hendrix, and E. Albrecht, "The Plutonium-Carbon System," Int. Conf. on Plutonium Metallurgy, Grenoble, April, 1960.
64. E. Bernsohn, J. Duffy, C. Leeper, and M. Silberstein, "A Status Report on SDR," *Nucleonics* (May, 1959).
65. G. Sofer and J. Sapir, "Potential of Carbide Fuels in Fast Breeder Reactors," Trans. of American Nuclear Society Meeting, Vol. 3, No. 1 (June 1960).
66. Personal communication from M. Raber and G. Sofer, NDA (May, 1960).
67. A. Secrest, E. Foster and R. Dickerson, "Preparation and Properties of Uranium Monocarbide Castings," BMI-1309 (Jan., 1959).
68. F. Rough and R. Dickerson, "Uranium Monocarbide—Fuel of the Future?", *Nucleonics* (March, 1960).
69. F. Rough, A. Hare, R. Price and S. Alfant, "Irradiation of Uranium Monocarbide," *Nuclear Science and Engineering* (Feb., 1960).
70. H. Pearlman, "Effect on Radiation on Massive Uranium Carbide," Talk presented at the National Metal Congress, Chicago, Ill., Oct, 1959.
71. D. Turner, "Process Development of Uranium Monocarbide Fuel Slugs," NAA-SR-4904 (March, 1960).
72. *Nucleonics*, p. 23 (December, 1959).
73. R. Gray, W. Thurber and C. DuBose, "Preparation of Arc-Melted Uranium Carbides," *Metal Progress* (July, 1958).
74. L. Joseph, G. Sofer and L. Goldstein, "Natural Uranium Sodium-Deuterium Reactors," NDA 84-15, Vol. I (February, 1959).
75. "Survey of Initial Fuel Costs of Large U.S. Nuclear Power Stations," EEI-59-150, Edison Electric Institute, New York, N.Y. (December, 1958).
76. A. Amorosi and J. Yevick, "An Appraisal of the Enrico Fermi Reactor," 2nd UN Int. Conf. on the Peaceful Uses of Atomic Energy, p. 2427 (June, 1958).
77. "Carbide Fuel Development," NDA 2140-2 (October, 1959).

cracking and the introduction of fission products lower the thermal conductivity of the fuel material. Accurate in-pile thermal conductivity data on carbides are not available, but estimates made by Battelle Memorial Institute during irradiation of arc cast slugs indicate that the in-pile thermal conductivity in the range of 600-1,000°C is about 75% of the out-of-pile thermal conductivity.

Coefficient of expansion is also an important property to know for the design of dense ceramic fuels in metal sheaths. Materials made by different methods have shown different coefficients of expansion; in general the values are similar to those of UO_2. This means that under operating conditions, it will be easy to get a tight fit between UC and low coefficient of expansion sheaths, such as zirconium and niobium, but that tight tolerances or additional forming operations will be necessary to get a tight fit between UC and high coefficient of expansion sheaths, such as austenitic stainless steels.

Current research and development programmes on fuel carbides are planned to study the properties of UC made by various methods and having various compositions and structures. The coming years should bring considerable additional carbide data.

PREPARATION AND FABRICATION

Arc Melting

The majority of the carbide fuels that were evaluated until recently were made by arc melting uranium and carbon[26, 71, 73]. Tungsten, graphite and uranium-graphite electrodes have been used in vacuum, argon, and helium atmospheres. Castings have been made by pre-alloying buttons and remelting them several times to improve homogeneity; the buttons have been prepared by casting into a graphite mould of the desired shape yielding densities of 98% to 99.5% of theoretical. Skull melting is being developed by Battelle Memorial Institute and Olin Mathieson in order to be able to produce large batches of UC[68]; ingots up to 6 kg have been cast. The products and the process are still being evaluated. Some effort has been spent on induction melting and the process appears feasible[71]. PuC has also been made by arc melting[63].

The advantages of the arc melting method are that the material obtained is of high purity, high density and is cast in the final desired shape (except for grinding). The method has been costly to date, because good homogeneity could only be obtained by a large number of remelts. Scaling up the size of the operation produces problems generally associated with large castings. Criticality problems will limit the size of enriched uranium or plutonium melts.

Hot Pressing Metal and Carbon

Arc melting temperatures are not necessary to cause the reaction of

$$U+C \longrightarrow UC \text{ or } U+2C \longrightarrow UC_2.$$

The monocarbide can be made by reacting at 1,000°C.

The most extensive investigation of this reaction was made by French investigators[31]. They hot pressed calcium reduced uranium powder and graphite in vacuum at 900°-1,000°C and produced material of better than 98% theoretical density. A limited amount of work has been done by the Carborundum Company and NDA on hot pressing uranium metal powder and carbon employing uranium metal shot and powder made by hydriding and decomposing the hydride. Homogeneity has been a problem with the product.

PuC has been prepared by reacting PuHx with carbon at 800°C and Pu metal with carbon at 1,000°C.

The advantages of the hot pressing method are that a high purity, high density material is obtained in the final desired shape, without having to form the carbide powder, with subsequent milling, pressing and sintering operations as is necessary in processes described below. However, the method is costly because it is slow. The life of the hot press dies is also limited.

Reacting Metal with Hydrocarbon Gases

Some of the first UC produced was made by reacting uranium metal powder with methane[18]. The reaction

$$U+CH_4 \longrightarrow UC+2H_2$$

proceeds at 600-900°C. UC_2 is formed at the higher temperatures. Uranium is hydrided, the hydride is decomposed and the resulting powder is brought in contact with methane (or other hydrocarbon gases). A very fine particle size UC powder is produced.

A number of U.S. laboratories are now successfully pursuing this method of making powder which can subsequently be fabricated into the desired shapes by cold pressing and sintering, or hot pressing. High density bodies have been made by the cold pressing and sintering process. UC of 98% theoretical density has been produced in the laboratories of the Olin Mathieson Co. by cold pressing at 30 ton/in.^{2} and sintering at 1,700°C.

The advantages of the process are its low reaction temperature, the complete contact between a gaseous carburizing agent and the uranium metal powder, and the high density material that can be produced by subsequent fabrication. Disadvantages are that pyrophoric and reactive powder has to be processed into fabricated shapes, and there is a tendency to have unreacted uranium metal in the product which may be disadvantageous in some applications. Uranium metal may swell, melt, or react with the cladding during high temperature operation. On

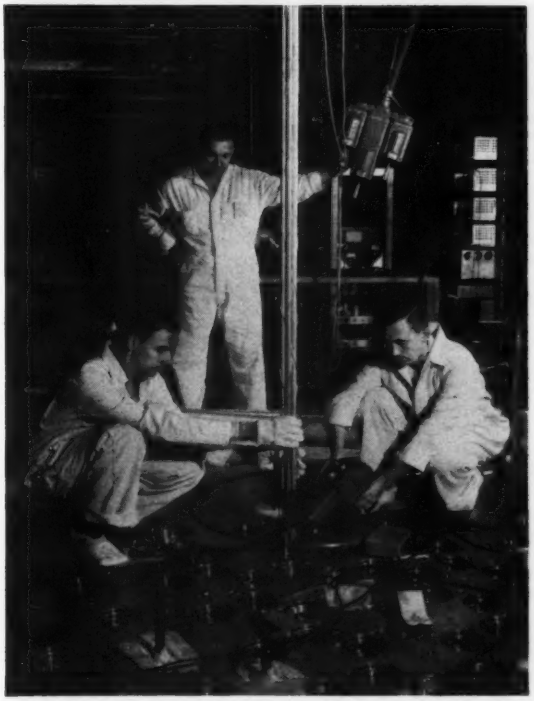


Fig. 2.—Loading a 7-rod fuel element into the SRE during early experiments to check mechanical fitness (Atomics International).

the other hand, it may increase thermal conductivity, density, and the fission product retention capability of the fuel.

Reacting UO_2 with Carbon

Both U.K.[29] and U.S. investigators have produced UC and UC_2 by the reaction

$$UO_2 + 3C \longrightarrow UC + 2\,CO$$

and

$$UO_2 + 4C \longrightarrow UC_2 + 2\,CO$$

The UC reaction starts at about 1,300°C and goes to completion rapidly (about 1 hour) at 1,800°C. The UC_2 reaction starts at about 1,900°C and goes to completion rapidly at 2,400°C. To obtain good contact between the UO_2 and carbon (or graphite) during the reaction, pellets of the mixtures are cold pressed and fired. The "clinker" of UC has a low density and must be milled to a powder, then fabricated into a dense body by any of the powder fabricating techniques. UC up to 95% of theoretical density has been produced in the laboratories of the Carborundum Company by cold pressing at 16,000 lb/in.^{2} and sintering at 1,800°C. A photomicrograph from a ½-in. diameter pellet is shown in Fig. 3. PuC has also been made by the PuO_2 and carbon reactions. The reaction goes to completion at 1,200-1,400°C.

The advantages of the process are that UO^2 is less costly as a starting material than uranium metal, and the product does not contain free uranium metal. Disadvantages are that pyrophoric and reactive powder has to be processed into fabricated shapes, and that the densities obtained to date have not quite matched the arc melted and methane reacted material.

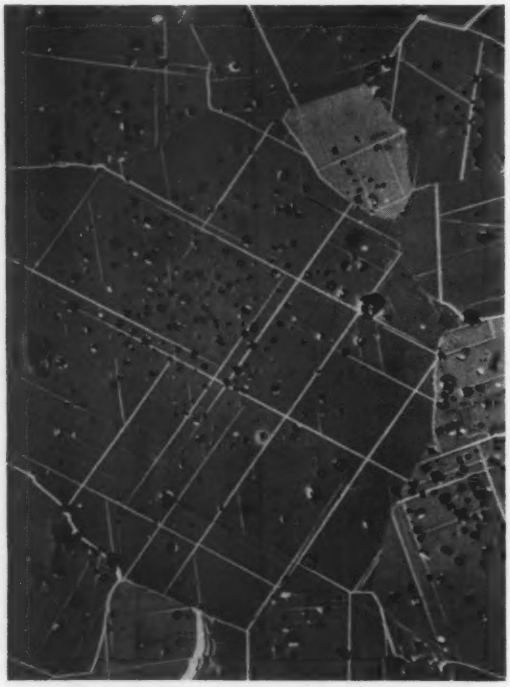


Fig. 3.—UC, pressed and sintered from powder. Etched with ⅓ nitric acid, ⅓ acetic acid, ⅓ water; grey phase is UC, white lines are UC_2, black and white dots are pores and UO_2 respectively.

GENERAL FABRICATION PROBLEMS

The major fabrication problems will be to fabricate a reproducible material and to do it economically. These problems, of course, are not peculiar to carbide fuels. However, a reproducible uranium carbide will probably be more difficult to obtain than a reproducible uranium oxide, simply because the carbide is so reactive and the impurities influence the structure. The choice of the most economical process cannot be made today, because of lack of experience. All fabrication to date has been on a laboratory scale. Only mass production experience will permit accurate cost analyses. The author's opinion is that the UO_2-carbon method of carbide synthesis followed by cold pressing and sintering (or swaging or vibratory packing) will be the most economical method of fabrication. Powder processing is less costly and more adaptable to mass production than arc melting, and the UO_2 starting material is less costly than the uranium metal required for the other processes. If carbide could be produced from uranium fluorides, the process might be more economical still. NDA and the Carborundum Co. are jointly producing and evaluating UC and PuC made largely by the oxide-carbon reaction[77].

COMPATIBILITY

Coolants

As shown in the data sheet, reaction with aqueous solutions is very rapid, much more rapid than the reaction of uranium metal and water. The reaction rate of uranium carbides with water is sufficiently high to exclude them from water or steam cooled reactors. Additions to uranium carbide may be found, which will improve the water corrosion resistance, but these "stabilized" carbides will have to compete with UO_2 in fuel density and thermal conductivity.

The corrosion resistance of carbides to Na and NaK appears to be good. Very little quantitative data are available as yet, but qualitative observations of arc-cast UC irradiated directly in NaK show some, but not serious, attack. Reaction of UC with Na or NaK coolant in the event of a cladding failure should not worry designers. Use of Na or NaK as a thermal bond between fuel and cladding requires further study.

Corrosion tests of carbides in organic coolants are few, but they indicate that a cladding failure would not produce an undesirable fuel-coolant reaction.

Corrosion of carbides in helium cooled reactors will be a function of oxygen and nitrogen impurities in the helium. As the helium will probably be quite pure, potential reactions should be negligible.

Uranium carbide corrosion data in CO^2 are also scarce. Limited tests show the rates to be similar or slightly better than metal.

Cladding Materials

Compatibility of carbide fuels with various metals is shown in the data sheet. Tantalum appears to be the least reactive material, followed by molybdenum and niobium. Austenitic stainless steels appear to be good, though some reaction has been noted. Nickel and nickel alloys react with UC, probably because of the solubility of nickel for carbon. Titanium and zirconium also react. Aluminium reacts rapidly with UC and UC_2 at elevated temperatures.

IRRADIATION BEHAVIOUR

All irradiation tests to date were made on arc melted UC produced by Batelle Memorial Institute for Atomics International. Exceptions are a few tests made by the U.K. some years ago on relatively low density UC, produced by

the UO_2+carbon reaction. The recent upsurge of research and development on UC is due in part to the success of the BMI tests and in part to the failure of metallic fuels to meet the requirements of sodium and gas cooled reactors.

Post-irradiation heating of a sample of UC irradiated to a low burn-up[55] released 0.7% of the Xe^{133} in 67 hours at 927°C. Plates of 24 w/o UC-stainless steel dispersions have been irradiated to 2-6 a/o burn-up and slight swelling of the plates was noted. The UC particles had some internal porosity after irradiation and the UC and stainless steel appeared to have reacted chemically. Temperatures were above 540°C but below 1,000°C[24].

Rough *et al.* reported[69] on the irradiation of arc cast UC up to 6,400 MWd/t at maximum surface and centre temperatures of 580°C and 1,000°C respectively. Density decreases of 0.6% to 2.5% were measured; some of the decrease may have been due to internal cracks. Fission gas release was calculated to be the amount that could be obtained by recoil from the fuel surface. Some surface attack was noted on all samples, apparently caused by oxygen contained in the NaK which was directly in contact with the fuel. H. Pearlman reported[70] on the irradiation of arc cast UC up to 14,000 MWd/t at fuel temperatures ranging from 540°C to 870°C with low density changes and fission gas release rates similar to previous irradiations. Samples irradiated to 20,000 MWd/t are due to be removed from the test reactor this summer. The data on arc melted UC show that the fuel is dimensionally stable and that it can retain fission products up to 1,000°C. The good results give rise to justifiably optimistic predictions which compare the potential behaviour of UC to the excellent irradiation behaviour of UO_2. Fuel carbide samples fabricated by arc melting and the other methods described will go in-pile at the end of this year; 1961 should bring us much additional irradiation data.

AREAS OF UNCERTAINTY

What further information does the reactor designer need to be able to design a reactor with carbide fuel? Here is a summary of the important unknowns answered only partially to date:

(1) The power level (what maximum temperature at what thermal conductivity?) at which carbide will operate without excessive dimensional changes.
(2) The fission gas retention ability at various temperatures.
(3) The compatibility with matrix and cladding materials.
(4) The permissible gap between fuel and cladding.
(5) The cost of fabricating and reprocessing the fuel.

The fuel fabricator will want to develop economical mass production methods to make a reproducible product available.

U.K. AEA's Sixth Annual Report

Expenditure : £92 million
Number of employees : 38,500
Steam generating heavy water reactor studies

THE sixth annual report of the United Kingdom Atomic Energy Authority covering the year March, 1959, to March, 1960, was published on July 14. The period under review saw the completion of all the main projects undertaken for the defence programme, the division of the Industrial Group into the Development and Engineering and Production Groups, and the transfer of Ministerial responsibility to the Minister for Science. The forecast for the following year's expenditure was £93,293,000, showing an increase of £860,000 over '59/'60; total number of employees increased from 35,260 to 38,500 in line with the policy of limiting the gross rate to a maximum of 8% per year.

In the section dealing with the Calder and Chapelcross reactors, mention is made of their greatly increased use for experimental irradiations, principally for reactor physics studies and fuel element proving tests in support of the civil power programme. Improvements in operating techniques have allowed a high utilization factor and the element ratings have been up-rated to the point where seven reactors are now running at a total power equal to that for which eight were originally designed. There would seem, therefore, to be a strong argument in favour of converting the eighth into a proper fuel element test bed as the present experimental facilities are limited and any experimental programme is overridden by the production programme. The three materials testing reactors provide certain high flux capacity for fuel element testing but statistical analyses require greater numbers to be handled and one of the military reactors could well be adapted for the purpose. Production of plutonium will, of course, not thereby stop but interruptions to operation would then be possible and a proper programme of experimental work could be laid down.

Production of fuel elements for the civil reactors is under way at Springfields, the first elements for Bradwell and Berkeley passing through just before the end of the period under review. Large numbers of prototype fuel elements have been made during the commissioning period of the factory, which has a capacity of 300,000 elements/an., and an oxide pellet production plant has also been set up and is beginning manufacture of AGR pellets for canning in the autumn. Complex inspection techniques on a large scale have been installed in the factory but it is recognized that considerable dividends are to be gained by improving these techniques to cut down waste time and unnecessary rejections. Greater production experience and operational behaviour correlations should also reduce fault rate.

The major construction programme at Capenhurst was completed in November last year but the output of the plant is not revealed and no indications are given of its capacity. No statement is made either of the adequacy (or otherwise) of the plant capacity to fill future requirements of enriched fuel for the civilian programme and no mention is made of the negotiations with the United States for the purchase of enriched uranium.

During the year the processing plant at Windscale has been modified to reduce the activity discharged from the works and so successful has this operation been that in spite of an increased through-put the total discharge was smaller than in the previous year. The new primary separation plant is under construction and this should come into operation in 1963.

Also at Windscale, work on the AGR has proceeded according to schedule backed up by much experimental and theoretical work including studies of control characteristics with a positive temperature coefficient. Consideration of this problem (particularly if beryllium is used as canning) has led to the technique of sweeping the moderator with the inlet gas so as to make the moderator temperature less dependent upon power.

Construction of the AGR at Windscale.

Of critical interest in the reactor is the carbon dioxide/graphite reaction. An evaluation of this has been aided by studies in BEPO where it has been demonstrated that the reaction is virtually independent of temperature up to 600°C; above this point the reaction rate increases rapidly. In sealed systems at intermediate temperatures, the concentration of carbon monoxide builds up to a steady state; the introduction of 1 to 2% of carbon monoxide in the AGR is likely to reduce the reaction and mass transfer to a negligible level. It has been proved that the amount of surface oxide present on the graphite also affects the rate, a result which tends to invalidate some previous experiments, as can also the effects of thermal and radiation induced degassing. Further work has also been done on the reactions between graphite and other gases such as nitrogen and hydrogen; below 650°C there is no measurable reaction with the former.

As regularly reported in these pages, great effort is being put into the development of beryllium and the manufacture of tubes and components has now been largely handed over to industry. It is too early yet to be certain of the behaviour of the metal under irradiation; whereas the MTR reflector, subject to very high dosages, lost all ductility, irradiations in the United Kingdom up to a few thousand MWd/t equivalent have indicated little change; these preliminary measurements are regarded as encouraging but much further research is necessary.

The Fast Breeder

The Dounreay Fast Reactor first went into operation in November of last year. Although no firm decision has yet been taken, the latest forecast for the building of a prototype is about 1967; following this, a commercial power station can be specified. To allow the rapid evaluation of different configurations from the physics standpoint, a new reactor ZEBRA is to be built at Winfrith. As the result of the commissioning trials of DFR it was decided to modify the core in order to allow more simple charge and discharge of experimental fuel element designs.

The possibility of the steam cooled heavy water reactor being developed by the Authority is still open and a decision can be expected in the autumn of this year as to the future of the project. From the original concept there has been a move towards the adoption of a pressure tube system in which, in effect, a double core is used. In the first section pressurized water is heated, is externally allowed to evaporate and the steam is then superheated in the second section; hence the new nomenclature SGHW, standing for steam generating heavy water reactor. It is claimed that the inclusion of the water heater lowers the capital cost by the elimination of the heat exchangers and by decreasing the investment of the heavy water. The physics of the system which are inevitably complex are being studied at Harwell in DIMPLE.

In their work on other reactor systems research has continued into the fundamentals of radiation breakdown of organics. To date no material has been found which offers for the organic moderated reactor a more resistant moderator/coolant than the polyphenyls adopted for OMRE. Investigations of the fully deuterated versions of these polymers have shown that while they are considerably more stable to electron radiation the increase in resistance to pile radiations is negligible and there is thus unlikely to be any economic advantage in adopting them in a power reactor.

As in previous years, the Authority has also been active in fundamental research and particular reference is made to the nucleon-nucleon reaction programme that is under way. One of the side results of this research has been the development of a new detector in which a p-n junction in a semiconductor such as silicon or germanium is used as a solid state ion chamber. High energy definition (½% resolution or better) is attainable in a small and simple device.

Industrial Isotopes

The industrial use of large radioactive sources is still in its early days, but the Authority for several months has been sterilizing 10,000 catheters a week in an irradiation unit using spent fuel elements from DIDO and PLUTO. Negotiations are continuing with industrial organizations for the installation of a production plant to carry out this work. It was reported last year that a company in Australia were to install a 150,000 curie source of cobalt for the sterilization of goats' hair (primarily against anthrax). This plant is to be further augmented with additional sources of up to 500,000 curies in strength. Sales of isotopes were up on previous years by 25%, the total value for the period under review being £1.1 million.

Whilst thermonuclear research from the academic point of view continues to make progress, from the exploitation angle it continues to give results both disappointing and perplexing. Increasing the gas current in ZETA up to 800 kA and operating with high gas pressures has not led to any substantial increase in temperature. Similarly, although the improved version of Sceptre III (Sceptre IV) has been operated at 480 kA it has not led to the production of higher temperatures. The next goal is the production of a machine with a very much higher rate of current rise and work has started at the Culham site on the buildings and associated facilities to house the Intermediate Current Stability Experiment. These should be completed next year and work will continue at the establishment to cater for a planned size of staff within four or five years of 1,000 people.

Work at Aldermaston

At AWRE research is continuing into the behaviour of linear pinches.

This has been greatly assisted by the development of very high-speed cameras which have been used to photograph the discharge looking along the axis of the tube. Analysis of the pictures allows the frequency of the sheath oscillations to be determined and for the general characteristics of the plasma to be studied. Confirmation is also obtained by magnetic probes placed on the tube axis.

A small group has been working on a machine based on the injection of 30 keV neutral atoms into an arc running along the axis of coils which provide the magnetic bottle. Associated research is concerned with the interaction between fast molecular and atomic hydrogen ions and hydrogen gas.

On the raw materials side, negotiations have been conducted to decrease the flow of uranium and arrangements similar to those adopted by the U.S. AEC for stretching out the current contract period have been agreed to. The report also makes mention of the fact that purchases of beryl ore were suspended during the year. Supplies of beryllium metal in the form of ingot powder and flake have been purchased from outside, mainly the U.S.A. but some from France. No reasons are given for this policy.

On the health and safety side, significant reorganization has taken place and courses for educating the new generation of health physicists and inspectors inaugurated. The Authority's own record continues to be of the highest order and this has been recognized by the acknowledgment of the trade union side of the National Joint Industrial Council who have congratulated the Authority on their achievements and have said that in their view the safety policies adopted are producing highly satisfactory results.

Part of the establishment from BR-3. BR-2 is on the left, BR-1 can be seen on the skyline, centre.

MOL and the C.E.N.

A Brief Survey of Research in Belgium

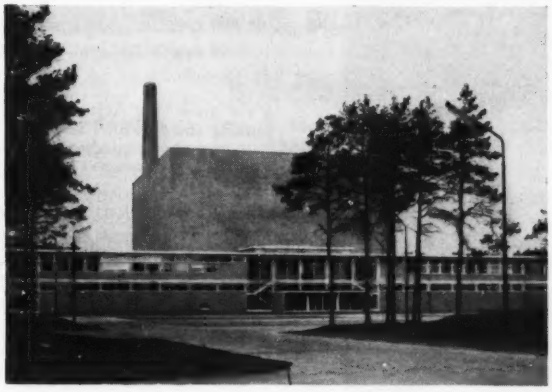
THE Centre d'Etude de l'Energie Nucléaire, Belgium's major organization in the nuclear field, was established as a public "utility" in 1957, by Royal decree. It took the place of an earlier body, the C.E.A.N., or Centre d'Etudes pour les Applications de l'Energie Nucléaire, which had been formed in 1951 as a non-profit-making association of notable personalities in ministerial, scientific, and industrial circles, with the object of promoting research.

In order fully to understand the position held by C.E.N. in Belgium's nuclear industry, it is as well to survey, briefly, the status and function of some of the other bodies in that industry which, at first sight, appear a little complex.

C.E.A.

The Commissariat à l'Energie Atomique was created by Royal decree at the end of 1950. The Commissioner's main concern is general policy, particularly in the international sphere, and the ensuring of co-ordination of activities in the nuclear field.

Co-ordination of nuclear activities is also the province of the **Service des Applications Nucléaires** of the Ministry of Economic Affairs. Also connected with the Ministry is the **Commission Nationale pour l'Etude de l'Utilisation Pacifique de l'Energie Nucléaire,** which is often referred to as the **Commission Consultative en Matières Nucléaires,** an advisory body which has, as its chairman, the Minister of Economic Affairs.



Neutron Physics, with BR-1 in the background.

I.I.S.N.

Founded as early as 1947, as the Inter-University Institute of Nuclear Physics, **l'Institut Interuniversitaire des Sciences Nucléaires** was given legal status as a public body. Its main function is the co-ordination and partial financing of fundamental research, and its governing body contains representatives of the Universities of Ghent, Liège, Brussels and Louvain; the Polytechnic School of Mons and the Royal Military Academy.

B.E.N.

While most of the above-mentioned are concerned with research and nuclear science in general, one or two bodies are specifically interested in power plants. The B.E.N., or **Bureau d'Etudes Nucléaires** was set up in 1956, as a limited company, by a group of power and traction companies. Its function is best described by the American term "Architect-Engineer" and the results of its work can be found in the description of the BR-3 reactor, elsewhere in this issue.

BelgoNucléaire

BelgoNucléaire, as the **Société Belge pour l'Industrie Nucléaire** is called, is a corresponding body, set up in 1957 by a group of manufacturers and industrial concerns. It is associated with B.E.N. in carrying out work on BR-3.

G.P.I.N.

The **Groupement Professionnel de l'Industrie Nucléaire** was founded by some 50 industrial concerns including chemical and metallurgical plants, electrical and mechanical engineering concerns, to further their interests in the nuclear field. It now has more than 80 members, and created the Fondation Nucléaire, which has achieved the status of a public body, with the object of promoting research. It assists in the financing of C.E.N.

The foregoing by no means exhausts the list of public bodies, companies, and associations in the nuclear field. This brief glimpse, however, may serve to put in perspective

NOTE: The expression "utility" has a legal significance in Belgium, and should not be confused with the U.S. usage, i.e., a power supply or transport company.

the C.E.N. (which, as the body concerned with applied research, may be regarded as the Belgian equivalent of the U.K. AEA), and its principal establishment.

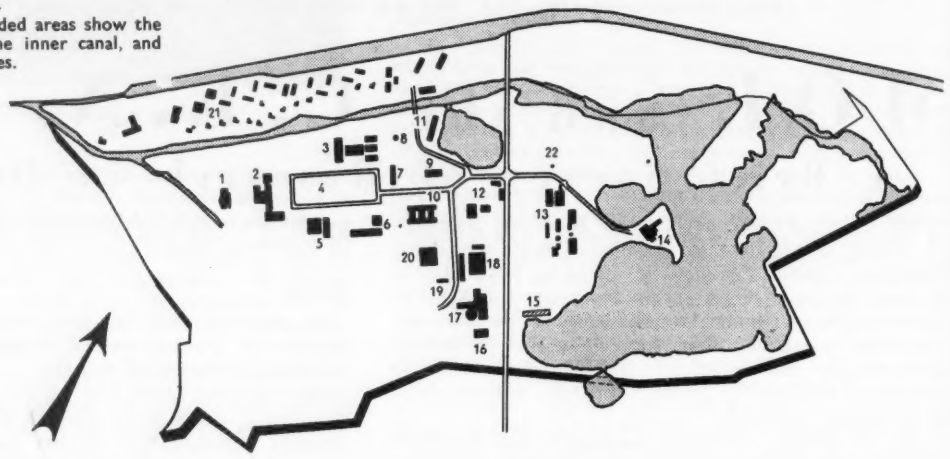
MOL

The activities of C.E.N. are largely concentrated near Mol, a town of about 25,000 inhabitants in the North-East of the Province of Antwerp, about 85 km from Brussels. Here in 1953, a site of 192 hectares (about 475 acres) was acquired; in 1958, a second site of 350 hectares (950 acres) was added, a few hundred yards away.

Both sites are bounded on the northerly side by the Scheldt-Meuse canal. No. 1 site has, also, extensive lakes or lagoons. Both sites are relatively well located for road communications and power supplies, and both sites were, originally, thickly wooded. Particular care has been taken that tree clearance takes place only where it is absolutely essential for buildings or access roadways; the result is not only particularly pleasing from the aesthetic point of view, it offers practical advantages in this rather flat and windswept part of the country.

At present, No. 2 site is relatively undeveloped, and will serve for extensions from time to time. Medical and radiobiological laboratories including the Euratom Central Bureau of Nuclear Measurements have been built there; the major part of C.E.N.'s activities are at present housed in No. 1 site, a plan of which is shown. Many of the departments are self-explanatory, and space will only permit of a short account of some of the features of outstanding interest. The future trend of the laboratory is the theoretical and experimental study of irradiation effects.

Plan of No. 1 site. Shaded areas show the Scheldt-Meuse canal, the inner canal, and the lakes.



KEY

1 Blower house for BR-1.
2 BR-1 and neutron physics laboratories.
3 Chemistry.
4 Substation No. 1.
5 Physics and electronics.
6 Health Physics.
7 Administration.
8 Water tower.
9 Conference room.
10 Metallurgical.
11 Club house.
12 Cafeteria.
13 Waste disposal.
14 BR-3.
15 Cooling towers.
16 Air cooling.
17 BR-2.
18 General workshops.
19 Substation No. 2.
20 Technology.
21 Residential area.
22 Heliport.

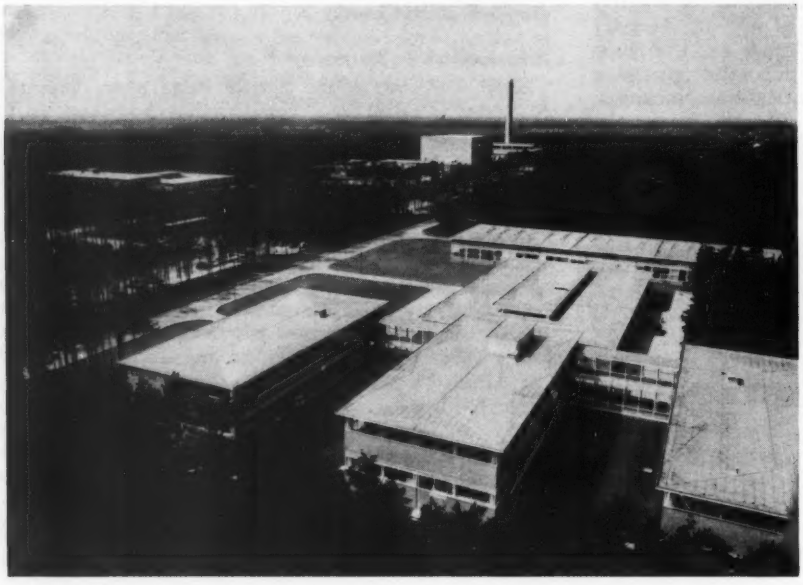
BR-1

Belgium's first reactor, BR-1, achieved criticality on May 11, 1956. It is an air-cooled graphite moderated pile, rather reminiscent of BEPO, with a thermal power of 4 MW. The moderator is a graphite cube of 7m (roughly 23 ft) sides, with 829 horizontal channels 5 cm square, and a total loading of some 27 tons of natural uranium, in aluminium canning. Cooling air, at the rate of 90 m^3/sec (approx. 190,000 ft^3/sec) is provided from a separate blower house, the air being discharged to a stack 60m (197 ft) high through filters.

The main neutron physics department is also located in the same building.

BR-2

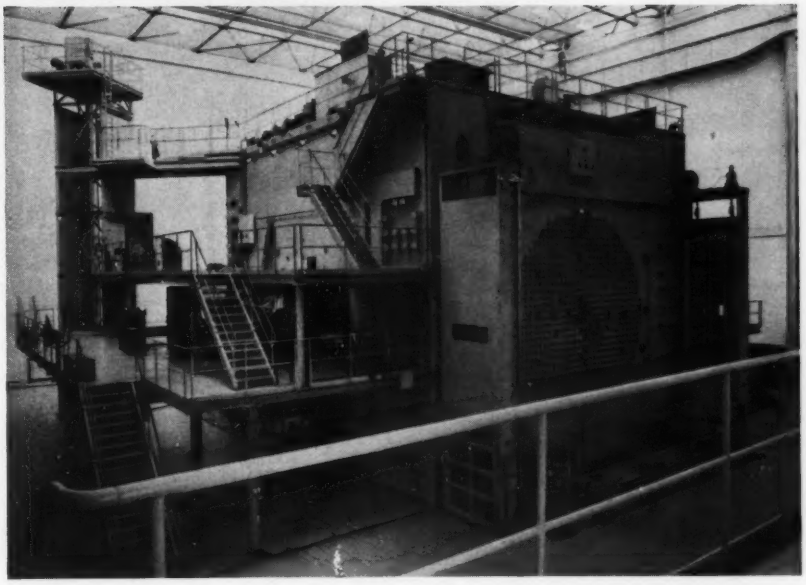
This reactor, intended for high flux materials testing, was originally described in a Geneva paper* which was briefly summarized in *Nuclear Engineering* for October, 1958, p. 434. As will be recalled, it has many interesting design features, not the least of which is the "hour-glass" arrangement of the fuel and experimental channels, providing a compact core with facilities for locating experiments well within the core while still allowing reasonable clearance between the channel ends.



View from the water tower, looking towards BR-1 across the chemistry buildings.

* BR-2—The Belgian Materials and Engineering Test Reactor. Paper No. 1679, by H. Dopchie and J. Planquart.

Combining many features of tank and pool reactors, it is of 50 MW capacity (flux in the region of 7×10^{14} n/cm^2, sec), and is partly moderated by beryllium. Designed jointly by the Nuclear Development Corporation of America and a Belgian team of specialists, it is expected to go critical at the end of 1960, construction being well advanced.



BR-1 reactor from the control gallery.

BR-O2

BR-O2 is the zero-energy (about 100W) facility corresponding to BR-2 and, in addition to giving much information about BR-2 before it is completed, will be used for experiments to determine flux configuration before placing the experiments into the main reactor. It consists of an exact duplicate of the core of BR-2, located in a pool. Since it will not operate at above 100W it does not require cooling other than the pool in which it stands, and the only circulation is in the form of a comparatively small purification loop.

BR-2 and cooling towers during erection.

BR-3

Belgium's first power experiment, the BR-3, is fully described elsewhere in this issue.

Neutron Physics

The neutron physics department, in addition to what might be termed "routine" work carried out in BR-1, is also concerned with the preliminary work on BR-2. They will also be in charge of the pre-critical experiments in BR-3, but they are, of course, more directly interested in the research reactors, one of their most important tasks being to analyse neutron dosimetry before experiments are placed in the reactors.

This department also has a research contract with the I.A.E.A. to determine a non-destructive method of estimating the amount of plutonium in irradiated fuel elements.

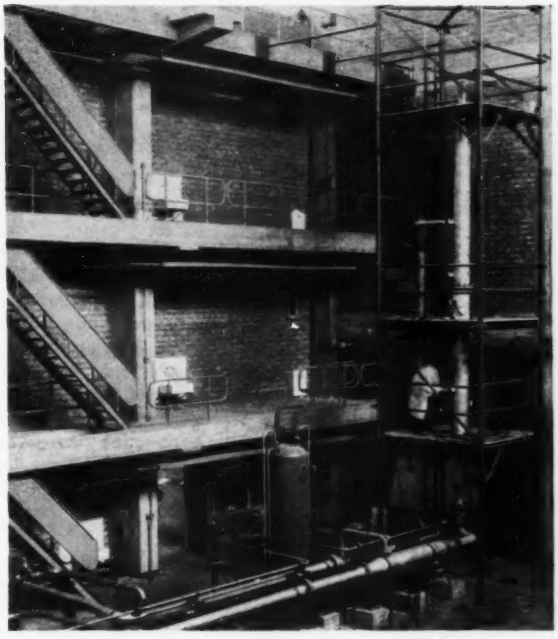
Technology Department

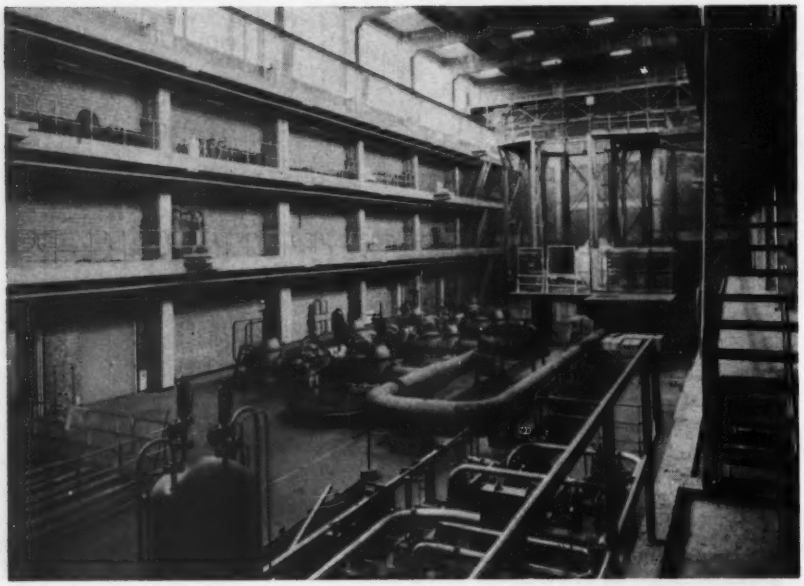
The main concern of this department is reactor technology; in-pile and out-of-pile loops, heat transfer problems, and the technique of "hot" manipulation. Loop work covers preliminary and detail design, construction, installation on the reactor, and dismantling, while heat transfer work covers gas, water, liquid metals and organics.

The development programme in progress on BR-2 is impressive in its thoroughness. Acknowledging that the design is "advanced," C.E.N. is setting out to eliminate as many troubles as possible before the reactor itself is complete. Hence the meticulous development programme. In addition to the construction of BR-O2 for the nuclear work, there will be three or more corrosion loops (aluminium, stainless steel, and beryllium). There is also an hydraulic loop with two reactor channels to test all the equipment which will go inside the channels.

More impressive still is a full-size mock-up of the reactor vessel and core, with all the equipment (channels, fuel elements, control rods and experimental capsules) in complete mechanical detail, along with the primary cooling circuit (using the pumps which will be used in the

Hydraulic test loop for BR-2 fuel channels.





Left: Part of the main Technology laboratory, showing the BR-2 full-scale mock-up with main coolant circuit and pumps, during erection.

Below: Mock-up of BR-2 vessel during erection of test rig.

reactor). This, together with the two-channel hydraulic loop, will enable a complete range of tests to be made on the hydraulic characteristics of the core, as well as vibration tests and stress measurements; it also enables accurate measurements to be made of the drop time of the control rods, and the stresses involved. Manipulation, too, has not been overlooked; a cylindrical tank has been built above the head of the vessel to contain water to the full depth of the pool, and an operating gallery at the top enables long-tool operating techniques to be practised and examined.

Metallurgical Department

In addition to the routine work proceeding in the metallurgical laboratories, interesting projects in train include some work on the zone-refining of plutonium, and the "stabilization" of Belgian uranium. Work in progress for Euratom includes a study of method to prevent the diffusion of aluminium into uranium, and work on plutonium recycling.

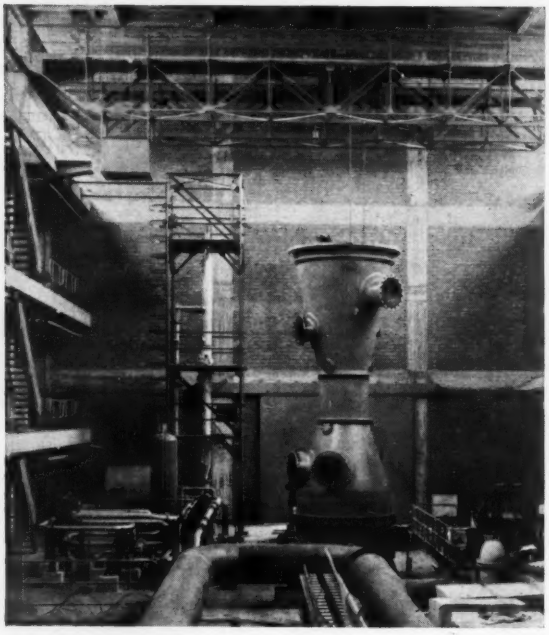
Work is also in hand on manufacturing techniques for BR-2. It is hoped to evolve cheaper manufacturing processes for the clad plates than the extremely expensive "picture-frame" process, and both casting and co-extrusion are considered as possible alternatives.

Chemistry Department

The chemistry programme includes three contracts with Euratom; one, for the reprocessing of plutonium and uranium by fluorination and chlorination; a proposal for manufacturing fuel elements from a mixture of plutonium oxide and uranium oxide; and a trans-plutonium project. There is also work in association with a Belgian chemical company on the synthesis of chemicals under radiation; the ultimate aim being the simultaneous production of chemicals and power. Some work is also proceeding on fission product separation (e.g., the production of I^{131}), and on radiation chemistry (e.g., the fundamental behaviour of free ions produced by radiation).

General

At present, waste disposal presents no great problems and low-activity wastes in liquid form are suitably diluted and treated before being discharged to the river. Solid and high-activity wastes are treated by several different processes. The waste disposal plant has been made larger than necessary to meet the immediate needs to take care of the Eurochemic plant which is being built on a nearby site.



About 1,000 persons are employed at Mol; approximately two-thirds being scientists and technicians. Many live on the site; the residential area, between the Scheldt-Meuse canal and the "inner" canal, contains accommodation of several types; houses, apartments, single rooms, and even its own school for younger children. There are excellent sports facilities.

Thanks are due to M. E. Symon (manager, C.E.N.) and M. G. Stiennon (assistant director of the Mol Laboratories) for assistance in obtaining the information contained in this article.

Boundary Conditions in Slab Lattices

by A. JEFFREY, M.Sc.
(*Senior Mathematician, Rolls-Royce, Ltd.*)

A surprisingly simple method of approximating boundary conditions near control surfaces in a small power producing reactor

WHEN using diffusion theory methods it is often necessary to use some approximation to deal with regions in which diffusion theory will not apply. Such regions are those in which absorption is high and in the vicinity of interfaces connecting two regions of very different nuclear properties. The method usually used is to replace a region of strong absorption by an appropriate boundary condition at the interface bounding that region. This well-known technique was used earlier [1] where the situation examined was the determination of the boundary conditions appropriate to an interface bounding an infinite surrounding region and an infinite plane slab of absorbing material. The infinite surrounding region on both sides of the slab was assumed to be composed of scattering and absorbing material containing uniformly distributed sources. The behaviour of neutron flux and current at the interface was indicated and two interpretations given for the usual boundary condition used at the interface with numerical results for these extrapolation lengths over a wide range of material and slab properties.

The absorbing slabs discussed in reference (1) were assumed to be in an infinite surrounding medium and it is appropriate that the results should be extended to take into account the finiteness of lattices. The present article considers how simple transport calculations for a scattering and absorbing slab may be interpreted to yield useful diffusion theory boundary conditions yielding correct neutron current. We start then by recalling some definitions relating to the mono-energetic transport equation that is the basis of our solution.

$$\mathbf{\Omega} \cdot \mathbf{grad}\ \psi + \psi/l = \frac{c}{4\pi l}\iint \psi(\mathbf{r}, \mathbf{\Omega}')\, d\mathbf{\Omega}' + S(\mathbf{r}, \mathbf{\Omega}) \quad . \quad . \quad (1)$$

where $\mathbf{\Omega}$ is the unit vector in the direction of neutron motion

$\mathbf{r}$ is the position vector of a neutron

S is the angular distribution of neutron sources

l is the total mean free path

$\psi(\mathbf{r}, \mathbf{\Omega}')$ is the flux of neutrons per unit solid angle in the direction $\mathbf{\Omega}'$ at point $\mathbf{r}$

$c = \dfrac{\Sigma_s}{\Sigma_a + \Sigma_s}$ is the mean number of secondary neutrons per collision

Σ_s is the macroscopic scattering cross section

Σ_a is the macroscopic absorption cross section.

We associate with this equation the simpler diffusion theory equation which is used to approximate the neutron flux and current behaviour,

$$D\nabla^2 \varrho - \Sigma_a \varrho + S = 0 \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where D is the diffusion coefficient

S is the neutron source per cm³ sec

and ϱ is the neutron flux.

Dividing through equation (2) by D the diffusion coefficient and defining L the diffusion length by the usual expression

$$\frac{1}{L^2} = 3\,\Sigma_a(\Sigma_a + \Sigma_s)$$

where $$D = \frac{1}{3(\Sigma_a + \Sigma_s)}$$

gives as an alternative to equation (2), the expression

$$\nabla^2 \varrho - \frac{1}{L^2}\varrho + \frac{S}{D} = 0 \quad . \quad . \quad . \quad . \quad (3)$$

where the diffusion theory expression for current is

$$\mathbf{j} = -D\ \mathbf{grad}\ \varrho$$

where ϱ is the solution to equation (3) subject to appropriate boundary conditions. The behaviour of the transport flux and current which are derived from equation (1) was indicated in reference (1) and introduced a new interpretation for the usual extrapolation length boundary condition of the form

$$\left[\varrho(\mathbf{r}) - \lambda \frac{\partial \varrho(\mathbf{r})}{\partial \mathbf{n}}\right] = 0 \quad . \quad . \quad . \quad . \quad . \quad (4)$$

on boundary $\mathbf{r}$ where $\mathbf{n}$ is a unit normal vector.

Frequently it is not the correct asymptotic flux behaviour that is of interest, but the neutron current at the plate surface. This situation is the case when control effectiveness problems are of interest and the absorbing plate is some form of control absorber. We now derive the modified extrapolation length $\overline{\lambda}$ introduced in reference (1) but corresponding now to a finite plate separation as in a lattice. The expression derived for $\overline{\lambda}$ is such that it gives correct neutron current entering the plate surface.

Application to a Lattice Problem

The modified extrapolation length $\overline{\lambda}$ will now be derived for the problem illustrated in Fig. 1.

A slab is considered of physical thickness $2a$, the centre of which is separated by a distance $2b$ from the centre of similar adjacent slabs in an infinite lattice arrangement. The absorbing slab is assumed to be composed of scattering and absorbing material with the ratio of scattering to total cross

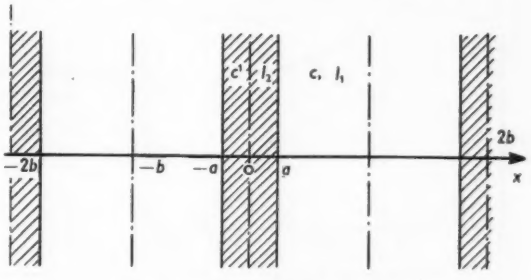


Fig. 1.—General lattice layout.

section c', and the medium surrounding the slab is assumed to have uniformly distributed sources and a ratio of scattering to total cross section equal to c. The mean free paths in the slab and the surrounding material are denoted by l_2 and l_1 respectively. The derivation of the modified extrapolation length is then achieved as follows. Using a spherical harmonic solution of equation (1) we derive the flux and the current into the slab at the interface $x = a$. Then, using the diffusion equation (3), the boundary condition (4) and the expression for neutron current

$$\mathbf{j} = -D \ \mathbf{grad}\ \varrho$$

an expression is derived connecting λ, hereafter denoted in its modified form by $\bar{\lambda}$ and the current. Using numerical calculations for the flux and current enables $\bar{\lambda}$ to be determined. Use of the Hurwitz-Roe method as given in references (2) and (3), enables the results for an infinite slab in a lattice to be interpreted in terms of finite absorbing sheets and more complicated absorber geometries.

We proceed then with the derivation as follows for the general case of a unit strength distributed source. Equation (3) has as the general solution the expression

$$\varrho(x) = A' \exp(x/L) + B' \exp(-x/L) + L^2/D$$

or, alternatively by rewriting A' and B',

$$\varrho(x) = A \cosh(x/L) + B \sinh(x/L) + L^2/D.$$

At $x = b$ we require by symmetry that

$$\left.\frac{\partial \varrho}{\partial x}\right|_{x=b} = 0$$

which gives the relationship

$$A \sinh(b/L) + B \cosh(b/L) = 0$$

At the interface $x = a$ we apply the boundary condition of equation (4)

$$\left[\varrho(x) - \bar{\lambda}\frac{\partial \varrho(x)}{\partial x}\right]_{x=a} = 0$$

yielding

$$A\left[\cosh\frac{a}{L} - \frac{\bar{\lambda}}{L}\sinh\frac{a}{L}\right] + B\left[\sinh\frac{a}{L} - \frac{\bar{\lambda}}{L}\cosh\frac{a}{L}\right] = -\frac{L^2}{D}$$

Solving these two equations for A and B yields for the flux $\varrho(x)$, the expression

$$\varrho(x) = L^2/D\left\{1 - \frac{\cosh[(b-x)/L]}{\cosh[(b-a)/L] + \frac{\bar{\lambda}}{L}\sinh[(b-a)/L]}\right\} \quad (6)$$

The neutron current given by the expression

$$\mathbf{j} = -D \ \mathbf{grad}\ \varrho$$

may be written by use of equation (6)

$$\mathbf{j}(x) = \frac{-L \sinh[(b-x)/L]}{\cosh[(b-a)/L] + \frac{\bar{\lambda}}{L}\sinh[(b-a)/L]}.$$

At the interface $x = a$ this reduces to the following simple result

$$\mathbf{j}(a) = \frac{-L}{\coth[(b-a)/L] + \bar{\lambda}/L} \quad . \ . \ . \ . \ (7)$$

which is the desired expression. This has the correct form for, when the half thickness $(b-a)$ of the surrounding material is large compared to L the diffusion length, then $(b-a)/L \sim 1$ and $\coth[(b-a)/L]$ approaches its limit of unity and equation (7) reduces to the well known formula for the semi-infinite surrounding medium case

$$\mathbf{j} = \frac{-L}{1 + \bar{\lambda}/L} \quad . \ . \ . \ . \ . \ . \ . \ . \ (8)$$

If $\mathbf{j}(a)$ and $\varrho(a)$ are computed by means of spherical harmonics from equation (1), then $\bar{\lambda}/l_1$ may be easily deduced by taking the ratio of equations (6) and (7) at $x = a$ to obtain

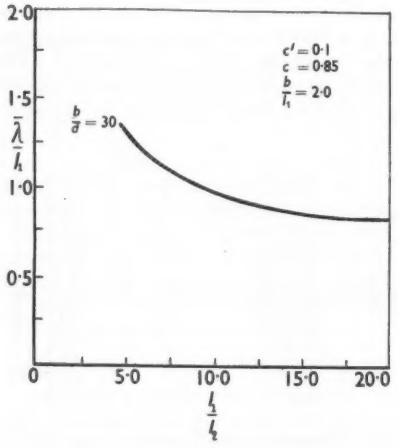
$$\varrho(a)/\mathbf{j}(a) = -\bar{\lambda}/D.$$

As $D = l_1/3$ this finally reduces to the very simple result

$$\bar{\lambda}/l_1 = -\tfrac{1}{3}\frac{\varrho(a)}{\mathbf{j}(a)} \quad . \ . \ . \ . \ . \ . \ (9)$$

The only difference between this result and the standard one is that here the flux and current are the actual flux and current and are not based upon the asymptotic flux behaviour. The calculation of $\bar{\lambda}/l_1$ is a simple process for a plane slab, but by appeal to the Hurwitz-Roe technique the results may readily be extended to non-trivial cases in which equation (1) could not be solved. A simple account of the P_3 spherical harmonic solution is to be found in Murray[4] in which our functions $\varrho(x)$ and $\mathbf{j}(x)$ are there denoted by N_0 and N_1 respectively.

If the absorbing slab is grey (i.e., has only absorption) then the method of spherical harmonics as outlined in Murray gives poor accuracy for high absorptions and a modification must be made. This is a straightforward matter and involves introducing an exponential attenuation in the slab and relating incident and emergent neutron



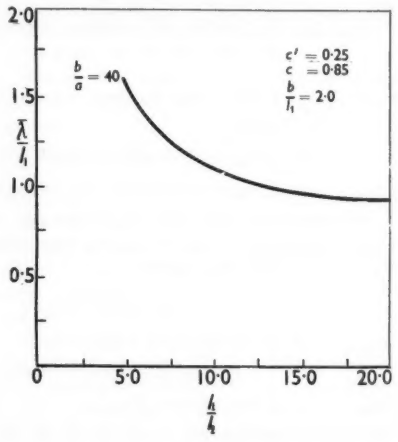


Fig. 2.—(a) and (b) Typical solutions for the equations derived.

angular fluxes $\psi(\mathbf{r}, \Omega)$. This method was suggested by Davison[5] and was used in reference (1) already quoted.

As the number of parameters required to specify a lattice problem of the type discussed here is five, being c, c^1, l_1/l_2, a/l_2 and b/a, it is not possible to present a tabulation covering the variation of all the parameters as this would present a prohibitive task. Consequently, by way of illustration of the type of result that may be expected when this method is used we present graphically in Figs. 2 and 3 the behaviour of $\bar{\lambda}/l_1$ for a few hypothetical slab lattices.

REFERENCES

1. Jeffrey, A., *J. Nuc. Energy*, Pt. A, 1960, XII, 1.
2. Hurwitz, H., and Roe, G. M., *J. Nucl. Energy*, 1955, 2, p. 85.
3. Stevens, H. E., *AEC Report*, TID–7532 (Part 1), 1957, p. 16.
4. Murray, R. L., "Nuclear Reactor Physics," Prentice Hall, 1957, p. 247.
5. Davison, B., "Neutron Transport Theory," Oxford University Press, 1957, p. 136.

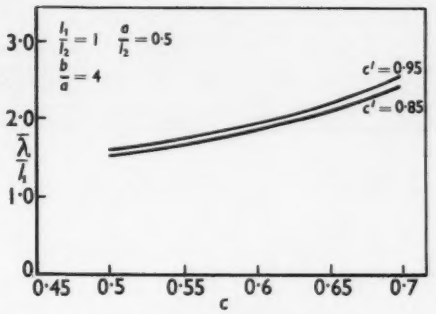
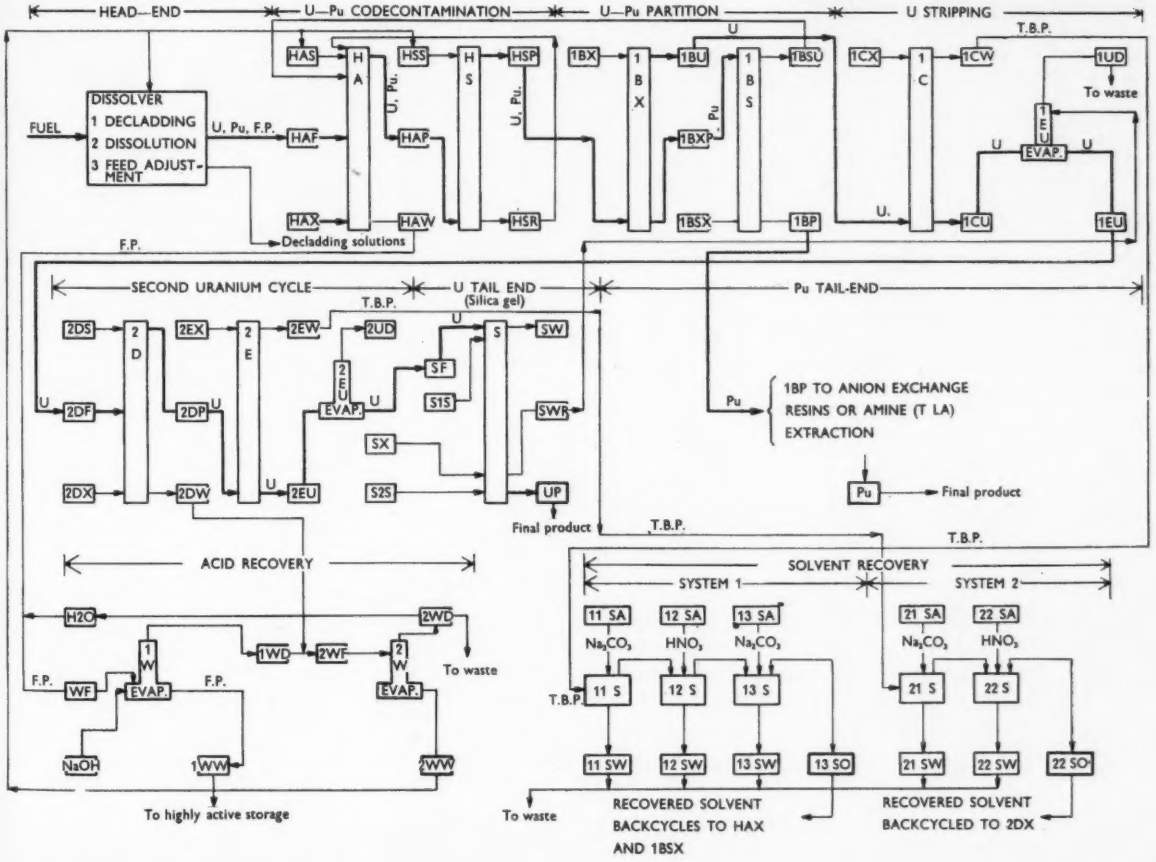
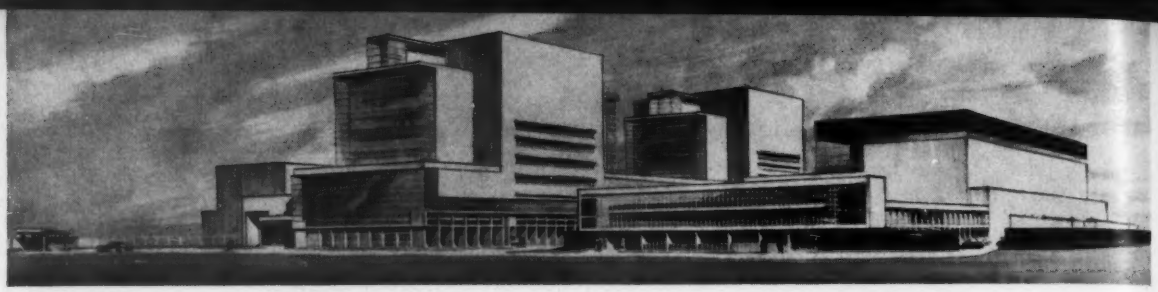


Fig. 3.—A further example of the effects of different parameters.

Eurochemic: Inauguration Ceremony

The ceremony inaugurating the construction of the Eurochemic plant at Mol in Belgium was held on July 7, when Prince Albert of Belgium placed in a stone plinth a symbolic fuel element containing, in place of the normal charge of uranium, a parchment recording the occasion. The plant (a description of which was given in *Nuclear Engineering* for last month, pages 295-298) will serve as a pilot unit for the construction of similar process plants to serve the civil stations when these come to be built. Although of only small capacity the project allows members from all the participating companies to gain experience of the techniques and processes involved. A flow diagram is reproduced below.





(Above) Artist's impression of the 550-MW TNPG design.

TNPG's design for Dungeness

A LETTER of intent has been sent by the Central Electricity Generating Board to The Nuclear Power Group as a preliminary to placing a contract for the construction of a 550-MW nuclear power station at Dungeness in Kent. Work on the site will begin in the next few weeks and the station is scheduled to come into operation during 1965.

The Nuclear Power Group comprises a union of the former consortia A.E.I.-John Thompson and the Nuclear Power Plant Company. The former is responsible for the construction of Berkeley in Gloucestershire, and the latter for Bradwell in Essex and in association with Agip Nucleare the Latina station in Italy. The design has been evolved by the new group from outlines originally prepared by the Nuclear Power Plant Company and includes a number of innovations introduced in the Latina design (*Nuclear Engineering*, October, 1959, pages 329-342).

Dungeness follows the pattern of the Board's previous stations, comprising two reactors of the CO_2 cooled graphite moderated natural uranium type. The main parameters incorporated in the design are listed in the accompanying table. The striking advance is in the thermodynamic efficiency which has been pushed up to 32.9% and is believed now to represent the maximum that can be achieved with Magnox cladding. The high efficiency and the high inlet temperature, chosen to be firmly above the temperature range at which Wigner energy can become a problem during the scheduled life of the reactor, give a clue to the process of optimizing the plant.

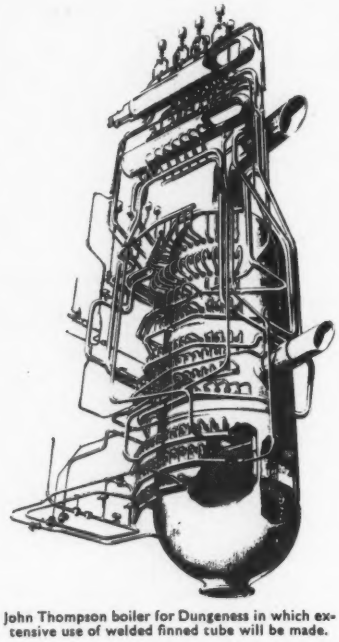
The main departures from previous practice relate to the steam cycle and the use of blowers directly coupled to back-pressure turbines driven by the high pressure steam, and the reduction of the number of main coolant circuits to four. The steam is generated in the heat exchangers at two pressures, the high pressure steam being fed to the back pressure blower turbines and returned to the heat exchangers for reheat, the reheated conditions being the same as those of the steam generated in the low pressure section. As a result there is a joint feed to the main turbines at a single pressure and temperature which results in considerable simplification of construction; the turbines will, in fact, appear very similar to those which were being installed in conventional stations 15 years ago. The main feed water temperature is 180°C.

The adoption of directly driven turbo blowers has important advantages from the safety viewpoint. In the event of a main power failure, the drive to the blowers is unaffected. Back-up pony motors are also provided which will assist under start-up conditions although arguments can be put forward for their exclusion, particularly as an oil-fired boiler will be provided on the station specifically for commissioning purposes but also as a reserve steam supply.

The increase in the inlet temperature has necessitated an increase in the coolant mass flow and the system pressure has been raised to 283 p.s.i.a. which probably represents the maximum practicable for this type of reactor. Reducing the number of main coolant circuits to four has allowed a more compact arrangement of inlet and outlet ducts and the pressure vessel is nearly 5 ft smaller in diameter than Latina (for a net electrical output 37% higher). Plate thickness has gone up to 4 in. but the material used will be carbon steel as before lined with metallic insulation canned in stainless steel.

It has not been found necessary to go to hollow fuel elements and with the more conventional solid rods a bulk outlet temperature of 410°C is achieved from a core somewhat flatter than the Latina core. The core construction does, however, differ in detail in that the stack will comprise octagonal blocks interspersed with squares keyed by T-sections in the sides and maintaining a square lattice pitch of 7¼ in. The core will rest on solid supports the provision of ball bearings having been rendered unnecessary. Charge and discharge remains from above from a remotely controlled compound machine.

Many detail improvements have been made in design, for example the BFE equipment whilst following the general pattern of Latina includes provision for rapid scanning of the channels (every 7 minutes) whilst simultaneously scanning slowly at high sensitivity. This is achieved by arranging for the selector valves (mounted in the stand pipes) to group channels together for the rapid evaluation whilst sending a separate feed for the precise measurement.



John Thompson boiler for Dungeness in which extensive use of welded finned tube will be made.

DUNGENESS—TECHNICAL DATA

PERFORMANCE :	
Net electrical output	550 MW
Heat output per reactor	835 MW
Efficiency	32.9%
Bulk coolant outlet temp.	410°C
Coolant inlet temp.	250°C
Nom. max. can surface temp.	442°C
Nom. max. uranium temp.	563°C
HP steam pressure at blower TSV	1,410 p.s.i.a.
HP steam temp. at blower TSV	392°C
LP steam pressure at main TSV	550 p.s.i.a.
LP steam temp. at main TSV	391°C
Feedwater temp.	180°C
FUEL :	
Number of fuel channels per reactor	3,876
Number of elements per channel	7
Overall length of fuel element	41.7 in.
Length of uranium rod	37.6 in.
Dia. of uranium rod	1.10 in.
Total weight of uranium per reactor	298 tonnes
CORE DIMENSIONS :	
Diameter of active core	45 ft 4½ in.
Height of active core	24 ft
Diameter of reflector	50 ft
Height over reflector	27 ft 10 in.
Lattice (square) pitch	7.75 in.
GAS CIRCUIT :	
Mean dia. of reactor vessel	62 ft 6 in.
General plate thickness	4 in.
Gas working pressure	283 p.s.i.a.
Number of gas circuits per reactor	4
Diameter of gas ducts	6 ft 6 in.
Power input per blower	7 MW
Overall height of boilers	75 ft
Internal diameter of boilers	23 ft 6 in.
Shell thickness (graded)	3⅜ in. to 2⅞ in.
TURBO-ALTERNATORS :	
Number of main turbo-alternators	4
Continuous maximum rating/set	142.5 MW
Speed	1,500 rev./min
Generator voltage	13.8 kV
Vacuum	28.9 in. Hg
Exhaust wetness	14.3%
Total circulating water quantity	353,000 gal/min
LAYOUT :	
Distance between reactor building centres	426 ft
Length of reactor building	316 ft
Length of turbine house, only	385 ft

Technical Papers and Publications

IAEA Symposium: "Fabrication of Fuel Elements with Special Emphasis on Cladding Materials," Vienna, May 10-13

Reported by Dr. V. W. ELDRED
(Research Manager D & E Group, R & D Branch, U.K. AEA)

THE symposium covered a wider field than its title suggests. The 50 papers presented were grouped into five sessions:—

I. Characteristics of Cladding Materials. Papers 20, 39, 19, 16, 5, 17, 21, 42, 9, 12, 51, 13, 14, 10 and 53.
II. Fuel Element Fabrication. Papers 50, 31, 40, 4, 8, 46, 22, 26, 24, 35, 3, 41 and 7.
III. Quality Control and Inspection. Papers 33, 15, 29 and 23.
IV. Corrosion and Radiation Damage. Papers 47, 28, 1, 11, 2, 25 and 34.
V. Economics and General Trends in Fuel Element Fabrication. Papers 37, 45, 36, 43, 30, 54, 38, 6, 27, 52 and 48.

Some papers dealt with several of these topics and their inclusion under a particular heading was merely an administrative convenience.

It is difficult to think of a more exacting fabrication problem than the simultaneous forming of a ceramic fuel with its metal can to the very high material and dimensional standards demanded for fuel elements. Nevertheless, promising results were reported[40] on the co-extrusion of UO_2 with stainless-steel cladding; an essential step in the process is to heat the fuel to a higher temperature than the cladding material before extrusion. In the search for simple methods for plutonium fuels fabrication, cold and hot swaging have been investigated and applied with some success to the forming of UO_2 with its cladding[48]. Swaging has also been used in Japan[23] to produce both rod and hollow types of experimental UO_2/stainless-steel elements. Until the results of large-scale irradiation trials are available, however, it is difficult to assess the success of such techniques, however ingenious. The same comment may be made about work described in other papers. Hardung-Hardung[37] of OEEC showed quite clearly that power costs would not be greatly affected by the foreseeable economies in fabrication and were much more likely to be influenced by the burn-up attainable.

A wide variety of specialized techniques for the fabrication of cladding materials has been used by the Fuels Development Group of the Hanford Laboratories[46]. The speed, simplicity and flexibility of vibrational compacting make the method very attractive for ceramic fuels; and, what is more, UO_2 elements formed in this way have shown excellent stability under irradiation[46].

Zirconium-base alloys, especially Zircaloy-2 and Zircaloy-4[29], with outstanding corrosion resistance in high-temperature water and steam, naturally received a good deal of attention. A German contribution[10] compared these Zr-Sn alloys preferred by the American with the Zr-Nb alloys favoured by the Russians and concluded that each had a definite field of application depending on the pressure and temperature; in the same paper the fabrication of Zircaloy in Germany was described. The investigations reported by Thomas[20] of Chalk River led to the conclusion that radiation embrittlement and hydrogen pick-up would not be serious in the Zircaloy cladding of the Canadian power reactors. In the production of Zircaloy tubes one of the biggest problems is the detection and elimination of cracks at external and internal surfaces[19]. Production control of Zircaloy cladding in Sweden for the R3/Adam reactor was described[15], and another Swedish paper[14] dealt in some detail with the method used for pickling Zircaloy-clad elements to give optimum corrosion resistance. In the production of highly rated elements for the Bettis PWR, bonding of Zircaloy to Zircaloy is achieved[50] by high-temperature inert gas pressurizing; reaction between the can and fuel, which is in the form of thin UO_2 platelets, is prevented by a thin interlayer of carbon or chromium.

The use of small welding chambers for the argon-arc sealing of individual Zircaloy cans was recommended[53] in preference to batch welding in large boxes with gas-tight gloves. Electron-beam welding of canning materials was referred to by several authors and one paper was specifically devoted to it[7]; this technique has several attractions, particularly if an evacuated element is acceptable. French experience in the automatic arc welding of magnesium alloys, including the welding of Mg-Mn to Mg-Zr alloys, was reported[31]; no major difficulties had been experienced. The conditions recommended by the Kjeller Research Establishment in Norway for the argon-arc welding of 0.010-in.-thick austenitic stainless steel tubes to end plugs were also described[25].

There is still some interest in aluminium and its alloys as a cladding material. In the Belgian reactor BR1 the uranium metal fuel is bonded to an aluminium can by a nickel interlayer[6]. Work is still being undertaken on the possible use of aluminium alloys for contact with high-temperature water[17]; satisfactory results have been obtained at 160°C but not at 210°C. But it will probably be in the form of SAP (sintered aluminium product) that aluminium will be of particular interest in the future. The claims made for it are almost too good to be true. The fact that it is inert to CO_2[21] is perhaps not surprising, but a very thorough series of tests would be required to convince most fuel element designers that it is compatible with uranium at temperatures up to 500°C[21] and lead at 400°C[52] under irradiation. By alloying, especially with Ni and Fe, the corrosion resistance of SAP in water and steam can be greatly improved[11]. The high temperature tensile and creep strength[21] of the material is much better than that of wrought aluminium. Possible disadvantages are that SAP cannot be fusion welded (although it can be pressure welded)[21] and that there is some uncertainty about the rate of diffusion of fission products through it[11].

Three papers were devoted to the compatibility of cladding materials with carbon dioxide. Baqué, Darras and Chevilliard[24] have studied, and have endeavoured to explain, the behaviour of specimens of magnesium and several magnesium alloys (including Magnox and Mg-Zr) in CO_2 at 25 and 60 atmospheres in the temperature range 400-600°C. All the alloys appeared to be satisfactory from the corrosion point of view at temperatures up to about 500°C, although Magnox generally showed larger weight gains than the other alloys. Unfortunately no attempt was made at a quantitative evaluation of pitting which is surely as important a criterion of deterioration as weight change in a canning material, especially magnesium; nor was there any attempt to compare the relative merits of the different alloys under fault conditions. This paper is nevertheless an interesting report on a large volume of work. The outstanding conclusion from the work reported by Smith[1, 2] from Australia was that work-hardened surfaces of stainless steel (under 1-16 atmospheres pressure at 550-700°C) and beryllium (in wet gas at 700°C) suffered less corrosion in CO_2 than etched surfaces; the precise reason for this was not known although tentative suggestions were put forward in the case of stainless steel. While on the topic of gas-cooled reactors, reference may be made to one in which no corrosion problems will presumably arise[45]. In the graphite-moderated and helium-cooled reactor now under construction at Oak Ridge the surface of the UO_2 pellets (clad in stainless steel) will operate at 700°C and the gas outlet temperature will be about 570°C. As might be expected, the two major uncertainties about the behaviour of these elements concern the gas evolution from the fuel and the effective creep ductility of the can as it is deformed by the internal gas pressure in the reactor.

There was no doubt about the enthusiasm of the German delegates for graphite as a canning material[9, 13, 18]. The development of both artificial[13] and natural graphites[9] of high density and low gas permeability was described, but there appeared to be some difference of opinion between the authors on the relative merits of the two types. An immediate incentive for this work lies in the manufacture of elements[9] for the gas-cooled high-temperature reactor under development by BBC/Krupp. Initially these elements will consist of an impermeable graphite ball 2.4 in. in diameter with a cylindrical hole containing uranium carbide and graphite mixed to give a U : C ratio of 1 : 45. The compressibility of the comparatively porous fuel is believed to be sufficient to avoid trouble due to thermal expansion differences between the core and the outer casing. The reactor will later be used to test elements in which the fuel is homogeneously distributed through the graphite ball. Independent work on the impregnation of graphite by UO_2 for the Rebus experimental reactor was described in a Belgian contribution[3].

The materials and design of elements for a particular reactor are generally amenable to considerable modification in the light of experience, and a continuous process of development and improvement may be envisaged. Macherey[41] described this evolutionary process for the Experimental Breeder Reactor which is cooled by liquid metal.

The Mk.1 elements consisted of natural uranium in a stainless steel can (bonded with NaK), but the fuel was replaced, for the Mk.II element, by a 2 wt.% Zr-U alloy of better dimensional stability. An interesting point made in this connection was that, in contrast with experience on uranium metal, out-of-pile thermal cycling tests on uranium alloys (including U-Mo) gave only a poor indication of the irradiation growth behaviour. The present Mk.III element has the same alloy fuel bonded to a Zircaloy can, while in the proposed Mk.IV element a Pu-Al alloy will be used. The new element[20] proposed for the French reactor EL3 represents a very radical change in design. Each unit consists essentially of seven aluminium-clad UO_2 pencils arranged in a hexagonal (or "snow crystal") pattern. In addition to its primary purpose of increasing the reactivity available, the element will provide a vehicle for obtaining irradiation experience on ceramic fuel.

By coating small particles (40-300 microns) of UO_2 with ductile Cr, Nb, Ni, W or Mo and compacting them into a dense fuel material or embedding them in a metallic matrix, it is hoped to produce a fuel of high thermal conductivity and to retain fission products[18]; the same technique might be used with uranium metal particles to give a random structure of high corrosion resistance. The possibility of increasing the thermal conductivity of UO_2 by addition of Y_2O_3 is also being investigated[19]. Yttrium metal is now being produced in substantial quantities and has been used to line a loop in which uranium-chromium eutectic was circulating[23].

Leak testing of elements in France is carried out by external pressurizing in helium and the subsequent detection of escaping gas by a mass-spectrograph [22]. The risk of mechanical damage or deterioration after manufacture was considered sufficient to justify the setting up of an additional leak testing unit at the reactor itself. The importance of leak testing and examination of elements after irradiation was emphasized in a paper from Windscale[25] and further observations were reported on the behaviour of standard Calder elements. Other papers from the northern groups of the U.K.AEA included a review[27] of the development and organization of the fuel element manufacturing industry in this country and a description[26] of the facilities at Springfields for the fabrication of beryllium. The Dounreay contribution[24] was a joint paper with industry describing the manufacture of elements for DMTR.

Barnes'[28] description of lattice damage and gas formation in canning materials under irradiation was of a more fundamental character than many of the other papers, but it was clearly a subject of very real interest to those present and his lucid exposition was much appreciated. The other paper from AERE[29] consisted of an interesting description by Sharpe of the possible uses of microradiographs in the laboratory examination of canning materials and held promise of some interesting results to come.

An impressive gathering of this sort on a specialized topic has much to recommend it compared with the all-embracing Geneva conferences, although it is a pity that the Russians could not be persuaded to attend on this occasion. Detailed discussion would have been facilitated if the papers, complete with illustrations, had been issued well in advance. The staff of the IAEA should, nevertheless, be congratulated on the excellent manner in which they organized a stimulating and successful symposium.

Fuel Element Conference: Papers Presented

1. A. Draycott and R. Smith (Australia). "Compatibility of Austenitic Stainless Steel with Carbon Dioxide."
2. R. Smith (Australia). "Metallographic Observations on the Oxidation of Beryllium in Carbon Dioxide."
3. E. Jonckheere (Belgium). "Fuel Element Fabrication for REBUS Reactor."
4. E. Jonckheere (Belgium). "Cladding by Casting and Fabrication of Triplex Plates from U–Al Alloy."
5. D. Quataert (Belgium). "Transformation characteristics of Zirconium 15% Niobium Alloy."
6. D. Tytgat (Belgium). "Study of BR–1 Prototype Fuel Elements of Natural Uranium with Ni-Bonding and Al-Cladding."
7. J. van Audenhove, M. Meulemans, D. Tytgat and E. Jonckheere (Belgium). "Experiments with Electron Beam Welding of Canning Materials."
8. A. Boettcher, W. Krummeich, and G. Wirths (Germany). "Incorporation of Fuel into Gas-cooled High-temperature Fuel Elements."
9. K. Lipsdorf, R. Schaefer, G. Spener and E. Wege (Germany). "Reactor Graphite of Low Permeability and of High Density."
10. L. Bangert and K. Hennemann (Germany). "Zirconium and Zirconium Alloys for Water-cooled Reactors."
11. H. W. Schleicher, R. Weber and U. Zwicker (Germany). "Contribution to the Diffusion and Corrosion Behaviour and Creep Strength of Aluminium Powder Products."
12. E. Fitzer, K. W. F. Etzel, A. Pelz and O. Vohler (Germany). "The Development of Fine Grain Graphites with Low Permeability to Gases."
13. K. W. F. Etzel, E. Fitzer and A. Ragos (Germany). "Availability of Graphite for Reactor Use Especially for the Canning of Fuel Elements."
14. L. Hyden (Sweden). "Production Pickling Zircaloy Cladding."
15. L. Hellner, H. Mogard, B. Nelson, U. Nuström and G. Söderström (Sweden). "Production Control of Zircaloy Fuel Cladding."
16. G. Ostberg (Sweden). "Metallographic Study of Isothermal Transformation of Beta phase in Zircaloy–2."
17. K. Hannerz, R. Lindblad and A. W. Magnusson (Sweden). "Investigation of Some Aluminium Alloys as Cladding Materials in Water-cooled Reactors for District Heating and Process Steam."
19. G. H. Chalder (Canada). "Problems in the Use of Thin Zircaloy Cladding for Uranium Dioxide Fuel."
20. W. R. Thomas (Canada). "Zirconium Alloys for Water-cooled Power Reactors."
21. K. E. Mann (Germany) and B. Boudouresque (France). "Application of Sinter Aluminium as Cladding Material for Fuel Elements."
22. B. Prakash and N. K. Rao (India). "Fabrication of Fuel Elements at Trombay, India."
23. M. Yokosuka, S. Takahashi, Y. Honda and Y. Seki (Japan). "On the Sheath Defects of Swaged UO_2 Fuel Elements of Rod and Hollow Types."
24. M. McPhee, H. Lloyd and M. A. Warne (U.K.). "The Manufacture of Materials Testing Reactor Fuel Elements in the United Kingdom."
25. V. W. Eldred, J. Skinner and A. Stuttard (U.K.). "Post Irradiation Examination—An Essential Part of Fuel Element Assessment."
26. P. B. Eyre (U.K.). "Facilities for the Fabrication of Beryllium."
27. A. B. McIntosh, H. Rogan and J. D. Glanville (U.K.). "The Development of a Complete Power Reactor Fuel Industry."
28. R. S. Barnes (U.K.). "Radiation Effects in Cladding Materials."
29. R. S. Sharpe (U.K.). "Some Applications of Micraradiography to Fuel Element Inspection."
30. M. Gauthron and B. Guibert (France). "Study and Construction of the Fuel Element Snow Crystal."
31. P. Thomé and C. Bridoux (France). "Welding of Plugs and Shieldings made of Magnesium Alloys."
33. B. Blanc, S. Choumoff and M. d'Orival (France). "Tightness Control of Fuel Elements by means of Helium Liquation—The Case of the G2 Reactor."
34. P. Baqué, R. Darras and C. Chevilliard (France). "Compatibility of Various Magnesium Alloys with Carbon Dioxide Under Pressure Between 400 and 600°C."
35. R. H. Sövik (Norway). "Welding of Thin-walled Stainless Steel Tubing."
36. S. Aas (Norway). "A Low Cost Fuel Element for a Water-cooled Reactor."
37. H. Hardung-Hardung (OEEC). "Possible Fuel Fabrication Cost, Reduction v. kWh. Price."
38. M. J. Whitman (U.S.A.). "Exploratory Fuel Element Research."
39. J. Chirigos and S. Kass (U.S.A.). "Development of Zircaloy– 4."
40. A. Kaufmann and J. Hunt (presented by P. Lowenstein) (U.S.A.). "Extrusion of Clad UO_2 Fuel Elements at Elevated Temperature."
41. R. E. Machery (U.S.A.). "Fuel and Blanket Elements for the Experimental Breeder Reactors."
42. D. A. Douglas (U.S.A.). "Materials Research on Cladding for a Gas-cooled Fuel Element."
43. F. Forscher, F. M. Cain and B. L. Vondra (U.S.A.). "Coated Fuel Particles."
45. J. Rickert (U.S.A.). "Economic Consequences of Design Variations of Water Reactor Fuel Elements."
46. S. H. Bush (U.S.A.). "Unique Fabrication Processes Applied to Fuel Cladding Materials."
47. J. E. Minor (U.S.A.). "Irradiation Effects in Cladding Materials."
48. E. A. Evans (U.S.A.). "Novel Ceramic Fuel Fabrication Processes."
50. S. J. Paprocki, E. S. Hodge, P. J. Grisphover and D. C. Carmichael (presented by S. Dickerson) (U.S.A.). "Fabrication of a Compartmented Flat-plate Ceramic Fuel Element."
51. H. Pearlman (U.S.A.). "Cladding for Organic and Sodium Reactor Fuel Elements."
52. L. Biondi (Italy). "Research and Development Proposal for a Fuel Element Made up with Uranium Oxide Grains and Lead Mixture Contained in SAP Tubes."
53. G. Schneider (Germany). "Argonarc-Welding of Zircaloy–2 Tubes."
54. G. Fournet (France). "Nuclear Fuels for Power Reactors." (film).

U.S. AEC TID-8517, Civilian Power Reactor Programme, Part II. Economic Potential and Development Program as of 1959. (U.S. Government Printing Office, Washington 25, D.C. 70c.)

A summary of the present and anticipated economics of the reactor systems reviewed in TID-8516 and given detailed examination in TID-8518. An appendix shows the assumptions made in the calculations, some results of which are reproduced below.

NUCLEAR POWER GENERATION COST, mill/kWh

Reactor type	Fixed charges		Fuel cycle cost		Operation and maintenance		Nuclear insurance		Total	
	Now	Potential	Now	Potential	Now	Potential	Now	Potential	Now	Potential
Pressurized water	5.05	4.40	3.38	2.56	0.59	0.59	0.26	0.25	9.28	7.80
Boiling water	5.26	4.31	3.47	2.29	0.61	0.61	0.27	0.24	9.61	7.45
Light water moderated superheat	—	3.91	—	1.96	—	0.61	—	0.23	—	6.71
Organic cooled	4.39	3.53	5.72	1.83	1.09	1.09	0.25	0.22	11.45	6.67
Sodium graphite	6.11	4.47	4.12	2.00	0.70	0.65	0.29	0.25	11.22	7.42
Gas cooled (enriched fuel)	5.97	4.63	3.21	2.62	0.89	0.49	0.29	0.24	10.36	7.98
Fast breeder	5.10	4.43	7.10	1.99	0.79	0.79	0.26	0.25	13.25	7.46
Aqueous homogeneous	—	6.38	—	2.12	—	2.53	—	0.30	—	11.33
Heavy water	7.05	5.80	4.22	1.21	0.91	0.91	0.32	0.28	12.50	8.20
Gas cooled (natural U)	7.60	—	3.35	—	0.61	—	—	0.33	11.89	—
Coal-fired plants :										
35c/10⁶ B.t.u. fuel cost	3.31	—	3.32	—	0.36	—	—	—	7.0	—
25c/10⁶ B.t.u. fuel cost	3.31	—	2.37	—	0.36	—	—	—	6.0	—

Note : All plants are based on 300 MWe size—80% capacity factor—14% fixed charges.
The power costs are based on the equilibrium fuel cycle which will be 3 to 4 years after completion of construction.

TRANSLATIONS

A Résumé of Principal Articles

BR–3 (page 337).

BR–3 le premier réacteur de puissance à eau sous pression en Europe occidentale, est décrit dans une série de trois articles.

Le premier article est une description générale de l'installation et de certains des circuits auxiliaires. Dans le second sont considérées les principales caractéristiques du réacteur à la base de la conception et du système de contrôle. La seconde partie de cet article décrit un certain nombre de méthodes utilisées lors de la construction, y compris les séquences de bétonnage, la façon dont le programme a été agencé pour permettre la mise en place de l'équipement sans retarder les travaux de génie civil, ainsi que les nombreux essais d'étanchéité et de tenue à la pression de l'enceinte de confinement.

Le troisième article donne les principales caractéristiques du coeur et décrit les difficultés d'ordre métallurgique qui ont été rencontrées pour les éléments de combustible et pour les barres de contrôle ainsi que les problèmes de corrosion. Il est montré comment ces difficultés furent surmontées.

L'installation est la propriété du C.E.N. Westinghouse Electric fut le principal fournisseur d'équipement pour le réacteur. B.E.N. et BelgoNucléaire furent les architectes et ingénieurs conseils du projet.

L'utilisation de carbure d'uranium comme combustible (page 353).

Les carbures d'uranium combinent simultanément les avantages des combustibles métalliques et des combustibles à base d'oxide. Des essais de tenue aux radiations à une température de 800°C et pour un taux d'utilisation de 14000 MWj/t n'ont pas provoqué de déformations. Dans les mêmes conditions, les carbures d'uranium sont comparables au dioxyde d'uranium en ce qui concerne la rétention des produits de fission. La conductibilité thermique du carbure d'uranium est de huit à dix fois supérieure à celle du dioxyde. Elle est les deux tiers de celle de l'uranium métallique. La densité du carbure est supérieure de 24% à celle de l'oxyde. Elle est inférieure de 28% à celle du métal. Le principal inconvénient du carbure d'uranium est sa propension à l'oxydation. Notre collaborateur présente un excellent panorama des renseignements disponibles au sujet de ce matériau. Un tableau détaillé et de nombreuses références en constituent l'essentiel.

Les Conditions aux Limites pour les Réacteurs en Forme de Plaque (page 363).

A proximité des barres de contrôle, pour les petits réacteurs de puissance en particulier, il est difficile de déterminer les simplifications qui sont admissibles lors du calcul du flux et du courant de neutrons.

Une méthode simplifiée, basée sur la théorie de la diffusion et donnant des expressions simples déduites des conditions aux limites est décrite dans l'article considéré. L'application de cette théorie approchée est immédiate et simplifie considérablement les calculs neutroniques. Des solutions graphiques de divers cas particuliers sont également données.

B.R.3 (Seite 337)

B.R.3, das erste Experiment mit einem Druckwasser Leistungs-Reaktor in West-Europa, wird in drei Aufsätzen behandelt.

Der erste Aufsatz bringt eine allgemeine Beschreibung des Werks und einiger zusätzlicher Anlagen.

Im zweiten Aufsatz werden die charakteristischen Einzelheiten des Reaktors einer Betrachtung unterzogen, die bestimmend waren für den Entwurf und die Ueberlegungen bei der Einrichtung des Kontroll-Systems. Der zweite Teil dieses Aufsatzes beschreibt einige der Methoden, die bei dem eigentlichen Bau angewendet wurden, unter anderem die Reihenfolge, in der die verschiedenen Beton-Abschnitte gegossen wurden, die Methode, mit welcher der Aufbau des Werkes mit dem Fortschritt der Betonnierung in Einklang gebracht wurde, und die bis in's Einzelne gehende Prüfung des Haupt-Behälters in Bezug auf Druckwiderstand und Dichte.

In dritten Aufsatz wird die Kern-Konstruktion behandelt und die Schwierigkeiten metallurgischer Art, die sowohl bei den Brennstoff-Elementen als auch bei den Kontrollstäben auftraten, und wie diese zusammen mit den Problemen der Korrosion schliesslich überwunden wurden. Es werden ferner die Prüfungen beim Kritischwerden des Reaktors beschrieben.

Das Werk ist das Eigentum der C.E.N. mit Westinghouse Electric als der hauptsächliche Lieferant für den Reaktor. Ingenieure und Architekten waren für das Projekt B.E.N. und Belgo-Nucleaire.

Urankarbid als Brennstoff (Seite 353)

Urankarbid verbindet offenbar die Vorteile von metallischen Brennstoffen mit denen der Oxyde. Bestrahlungs-Versuche, die bis 14.000 MWd/t bei Brennstoff-Temperaturen bis zu 800° C gingen, zeigten, dass die dimensionelle Stabilität und die Fähigkeit Spaltungsprodukte festzuhalten mit UO_2 vergleichbar sind. Die Wärmeleitfähigkeit von UC ist ungefähr 8–10 mal diejenige von UO_2 und zwei Drittel von metallischem Uran. Die Dichte ist 24% grösser als die Dichte von UO_2 und 28% kleiner als die von metallischem Uran. Der hauptsächlichste Nachteil von UC ist seine Neigung zum Oxydieren. Unser Mitarbeiter bringt eine ausgezeichnete Zusammenstellung aller über das Material vorhandenen Daten, und ein besonderer Punkt der Darstellung ist eine umfassende Zahlentafel, die auch alle Referenzen enthält.

Grenzschicht Bedingungen in Platten-Gittern (Seite 363)

Insbesondere in kleinen Leistungs-Reaktoren ist es schwierig zu bestimmen, in welcher Art die Annäherungs-Berechnungen für Neutronen-Fluss und Strom gemacht werden müssen, wenn es sich um die Stellen handelt, die zunächst den Neutronen-absorbierenden Kontrollgliedern liegen.

Bei der Annäherungsmethode, die in dem Aufsatz gezeigt wird und die auf der Mathematik der Diffusions-Theorie beruht, wird ein überraschend einfaches Resultat für die Grenzschicht Bedingungen abgeleitet. Ihre Anwendung ist ohne weiteres gegeben und vereinfacht die Reaktor Berechnungen ganz beträchtlich. Graphische Lösungen typischer Beispiele sind angeführt.

B.R.3 (pág 337)

B.R.3, el primer experimento de reactor de fuerza hidráulica presurizado en Europa Occidental, se describe en tres artículos.

El primero ofrece una descripción general del plano y algunos de sus circuitos auxiliares.

En el segundo, se tratan características especiales del reactor, las que determinan el diseño y se considera la filosofía de control del reactor. La segunda parte de este artículo describe algunos de los métodos adoptados en la efectiva construcción, incluyendo el orden de la colada de las diversas secciones de hormigón, el método mediante el cual el montaje de la instalación fué correlacionado con el trabajo de hormigonado, y la comprobación complicada de presión y de fugas del recipiente principal.

En el tercer artículo se considera el diseño del núcleo y los contratiempos metalúrgicos encontrados tanto con los elementos de combustible como con las varillas de control y como estos, juntamente con los problemas de corrosión, fueron finalmente vencidos. También se describen las pruebas de criticalidad.

La instalación es propiedad de C.E.N. con Westinghouse Electric como el suministrador principal para el reactor. Los Arquitectos-Ingenieros del Proyecto fueron B.E.N. y BelgoNucleaire.

La Carburos de Uranio como Combustible (pág 353)

Los carburos de uranio parecen reunir las ventajas tanto de los combustibles metálicos como óxidos. Las pruebas de irradiación de hasta 14.000 MWd/t a temperaturas de combustible de hasta 800°C presentan una estabilidad dimensional y habilidad de retención del producto de fisión comparable a la de UO_2. La coductividad térmica de UC es alrededor de 8–10 veces la de UO_2 y dos terceras partes la del metal uránico. La densidad es 24% más elevada que UO_2 y 28% más baja que el metal uránico. La principal desventaja de UC es su propensidad a la oxidación. Nuestro articulista presenta una excelente recopilación de los datos disponibles sobre este material y una característica de esta presentación es una comprensiva hoja de datos plenamente referenciados.

Condiciones Limitrofes en Redes de Palastros (pág 363)

Particularmente en los pequeños reactores generadores de fuerza, es difícil en la región cerca de los absorbedores de control el determinar el tipo de aproximaciones que han de hacerse en el cálculo de flujo neutrónico y corriente.

En el método de aproximación demostrado en el artículo basado en la matemática de la teoría de difusión, se deduce un método sorprendentemente sencillo para las condiciones limítrofes. Su aplicación no representa ninguna dificultad y simplifica considerablemente los cálculos relacionados con reactores. También se incluyen soluciones gráficas de ejemplos típicos planteados.

Personal

Dr. P. Fortescue.

Mr. W. Boyd.

Mr. R. F. G. Lea.

Mr. D. A. Hubbard.

Appointments

Members of the new Governmental expert committee on safety problems involved in the development of nuclear science and engineering are: **Sir Alexander Fleck,** chairman; **Dr. T. E. Allibone, Mr. G. F. Bullock, Sir John Cockcroft, Mr. P. Connor, Dr. S. C. Curran, Prof. P. I. Dee, Prof. J. Diamond, Mr. F. T. Fletcher, Prof. J. E. Harris, Mr. F. Hayday, Sir Willis Jackson, Maj.-Gen. S. W. Joslin, Prof. J. M. Kay, Dr. J. Loutit, Mr. T. W. McCullough, Dr. A. S. McLean, Sir George McNaughton, Mr. R. E. Newell, Mr. H. N. Pemberton, Col. G. W. Raby, Mr. L. Rotherham, Sir William Slater** and **Dr. F. A. Vick.**

Mr. R. F. G. Lea as deputy chairman of CIBA and joint managing director with **Mr. D. A. Hubbard.**

Mr. J. C. Nutter and **Mr. R. Y. Parry** to the board of Isotope Developments.

Mr. G. C. Ottway as president of SIMA and **Mr. L. A. Woodhead** as vice-president.

Mr. J. Ritchie, Mr. J. Salter and **Mr. P. R. McGhee** to the board of Aluminium Corporation.

Mr. A. H. Woodley to the board of Keith Blackman.

Mr. T. H. Kelsey as deputy general manager of G.E.C.'s Witton Works.

Mr. H. A. Andrews as general manager of Power Auxiliaries.

Mr. J. D. Taylor to the board of Bell's Asbestos and Engineering.

Mr. J. D. D. Morgan and **Dr. L. M. Wyatt** to the research board of the British Welding Research Association.

Lord Plowden to the boards of British Columbia Power and British Columbia Electric.

Mr. W. M. Cann general manager of the newly formed Smiths Industrial Division.

Mr. E. C. Shackleton as assistant chief project engineer of the CEGB's Midlands Project Group.

Dr. G. L. J. Bailey as manager of research of Mond Nickel and **Mr. E. J. Bradbury** as superintendent of Mond's Development and Research Labs.

Mr. T. H. Cook as chief applications engineer of Morgan Crucible.

Mr. S. E. Dominey to the board of Northey Rotary Compressors.

Mr. W. W. Dolton has been re-elected chairman of the British Non-Ferrous Metals Federation.

Mr. R. Bavister as chairman of Alloy Steels Association.

Mr. B. Wright as sales manager of John Thompson Instruments.

Mr. G. Archer as president of Mond and Wiggin, **Mr. I. A. Bailey** as chairman; **Dr. L. B. Pfeil** as vice-chairman of Mond; **Mr. J. O. Hitchcock** as managing director of Mond and deputy chairman of Wiggin and **Mr. H. W. G. Hignett** as managing director of Wiggin.

Overseas

Dr. P. Fortescue as chief research and development engineer of the newly formed General Atomic Europe organization.

Dr. W. H. Zinn as a Fellow of the American Nuclear Society.

Dr. H. Hobson as director of the United Kingdom Scientific Mission in Washington.

Dr. V. L. Parsegian to another year's membership on the Committee on commercial uses of Atomic Energy, U.S. Chamber of Commerce.

Mr. V. H. Harris as manager of the new projects office of Vitro Laboratories.

Mr. G. J. Kangas, Mr. T. J. McDonald, Mr. R. K. Stiles and **Mr. L. E. Vlies** to the Allis-Chalmers nuclear department; **Mr. W. M. Johnson** as manager of the utility section and **Mr. C. S. Knox** as co-ordinator, data processing.

Mr. L. E. Link as an associate director of the reactor engineering division at the Argonne National Laboratory.

Vice-Admiral D'Escadre Joseph-Auguste Leurin as president of Dynatom; **Mr. J. L. Atwood, Mr. C. Starr, Mr. J. Pinczon** and **Mr. P. Loygue** to the board of directors.

Mr. W. Boyd as president of Arthur D. Little of Canada.

Mr. K. A. Lowe as chief resident engineer and **Mr. R. D. Harvey** as deputy chief engineer (electrical and mechanical) of British General Electric of Japan.

Mr. R. J. Beeley as deputy director, Sodium Reactors Department of Atomics International.

Mr. J. B. Adams, as director-general of CERN (part-time) in addition to being director-designate of Culham.

Col. G. B. Page, as assistant director for army reactors in the U.S.A.

Dr. J. C. Bugher, as director of the Puerto Rico Nuclear Centre.

Mr. E. V. Murphree, president of Esso Research and Engineering to the board of directors of the Atomic Industrial Forum.

Awards

Mr. J. B. Adams the Roentgen prize by the Justus Liebig University of Giessen, West Germany.

Dr. H. Brooks, Dr. J. S. Foster, Dr. I. Perlman, Dr. N. F. Ramsey and **Dr. A. M. Weinberg** the AEC's Ernest Orlando Lawrence Memorial Award for 1960.

Resignations

Mr. C. R. Prichard as director in charge of ICI's heavy chemicals group.

Mr. W. E. A. Redfearn as chairman of Alloy Steels Association.

Retirements

Sir Donald Perrott as Member for Finance and Administration of the AEA.

Mr. L. Bagrit from the board of Southern Areas Electric.

Mr. W. S. Cliffe as manager of Thos. Ward.

Mr. J. J. Gracie as director of General Electric.

Obituary

Nuclear Engineering regret to report the deaths of the following:—

Mr. F. C. Archer of General Electric on June 15 at the age of 62.

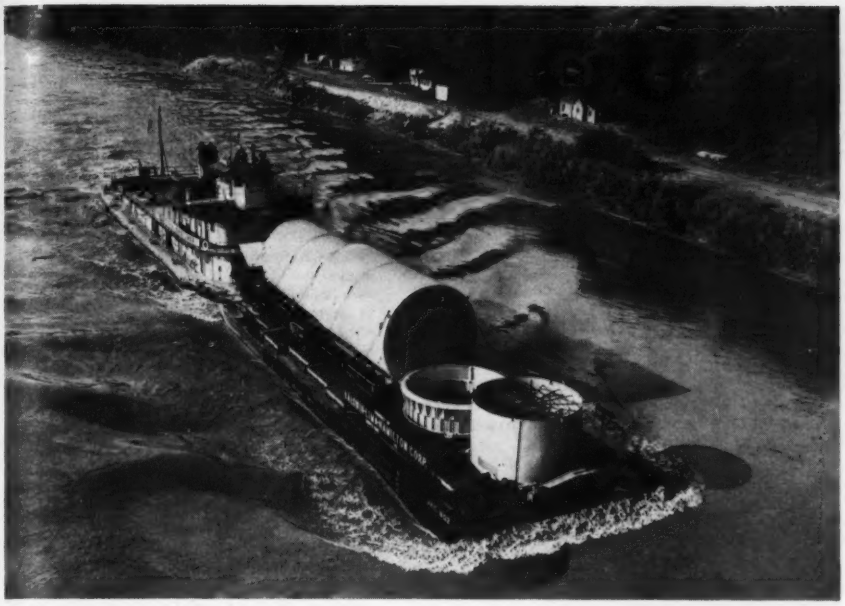
Mr. J. M. Rimington of The Distillers Company on June 19 at the age of 55.

Mr. R. D. Harvey.

Mr. K. A. Lowe.

Mr. W. M. Cann.

Sir Donald Perrott.



A barge containing the 80 ton vessel, 65 ton containment tank, 13 ton upper cavity liner ring and 4½ ton upper thermal shock liner ring for the Hallam nuclear power station, churning its way down the Missouri River. The 75 MW, sodium cooled, graphite moderated plant is being built by Atomics International for Consumers Public Power District of Nebraska.

World News

International

THIRTEEN STATES have been designated members of the IAEA board of governors for 1960-61. They are Australia, Belgium, Brazil, Canada, Finland, France, India, Japan, Poland, South Africa, USSR, U.K. and the U.S.A. The board comprises 23 members, 13 designated by the board and 10 elected by the general conference.

AN INCREASE of 8.5% has been proposed by the IAEA board of governors for the 1961 budget. The total budget is $7,968,000 and is divided into two parts, regular and operational. The operational budget will be $1,800,000 and the regular $6,168,000. The Agency has in addition $785,000 at its disposal as an estimated share of the funds of the United Nations Expanded Programme of Technical Assistance.

ASSISTANCE has been granted by the IAEA to 11 countries for the advancement of their nuclear energy programmes. $320,000 will be shared by the following countries: Afghanistan, Argentina, Brazil, Greece, Iceland, Israel, Philippines, Turkey, United Arab Republic, Sudan and Venezuela.

AN INDUSTRIAL FORUM, Foratom, has been formed by the nuclear industry of the six European Common Market countries for the exchange of ideas.

THE ANNUAL REPORT for 1959 has now been published by CERN. Copies may be acquired from the Scientific Information Centre, Geneva 23.

THE 16TH SESSION of the Council of CERN was held during June under the presidency of Mr. F. de Rose. The inauguration was also held of the Pauli Memorial Room, a library for the collection of the late Prof. Pauli's books.

United Kingdom

THE OFFER to purchase uranium on a 10-year contract from a mine (not yet in production) in Swaziland has been withdrawn by the AEA. Offers to buy uranium from Kenya, Uganda, Tanganyika and British Guiana have also been withdrawn. A 2½-year search for uranium in these areas has proved fruitless.

THE SIXTH ANNUAL REPORT of the Atomic Energy Authority has now been published and copies may be obtained from Charles II Street, London, S.W.1.

A ZERO ENERGY fast reactor, ZEBRA, is to be built by the AEA at Winfrith. The reactor is expected to be commissioned by 1962 and will be used to obtain information needed for the design of a prototype for the next step in the development of the fast breeder.

Australia

A NEW SERIES of hot cells costing £A500,000 has been opened at the Nuclear Research Centre at Lucas Heights.

Brazil

TWO INTER-AMERICAN meetings and an exposition were held in Brazil during July. They were the second meeting of the Inter-American Nuclear Energy Commission, the Third Inter-American Symposium on the Peaceful Applications of Nuclear Energy and the Inter-American Nuclear Energy Exposition. The U.S. AEC participated in all three.

NO DEFINITE SITE has yet been chosen but it is expected that tenders for a nuclear power station will be invited in October. It was originally planned to construct the station at Mambucaba, about 60 miles from Rio de Janeiro, but indications are that another site may be chosen.

A PILOT URANIUM PLANT is now functioning at the Atomic Energy Institute at São Paulo and is expected to produce about 30 kg of pure uranium per day.

Denmark

DANATOM have published a report on a comparative study of three 65,000 DWT tankers using nuclear, conventional steam-turbine and diesel-engine propulsion plants. The comparative construction costs are: nuclear, £4,961,000; turbine, £3,643,000; motor, £3,540,000.

Egypt

ENDORSEMENT for a request for an isotope centre in Cairo has been given by the IAEA. Requests for the establishing of similar centres in the Belgian Congo, Greece and Turkey are also being considered.

France

TECHNICAL DISCUSSIONS are continuing between the CEA and Euratom to decide the extent of the latter's participation in a research programme leading to the construction of a 25 MW(t) medium temperature gas cooled land-based marine reactor prototype.

West Germany

A LICENCE has been granted the Gesellschaft fur Kernenergieverwertung in Schiffbau und Schiffahrt to increase the power of their swimming pool reactor at Geesthacht from 200 kW to 5 MW. The reactor began operating in October 1958.

A REACTOR SIMULATOR will be supplied by Miles Electronics, U.K., to the nuclear research centre at Julich. It will be used for training personnel for the operation of the Merlin and Dido type reactors under construction at the centre.

COURSES in radiochemicals will be held by the Kernreaktorbau und Betrieb Gesellschaft at Karlsruhe.

Italy

CRITICALITY has been achieved by the RC-1 reactor at the CNRN Nuclear Studies Centre at Casaccia. The reactor is a 100 kW TRIGA Mark II, purchased from General Atomics.

THE GOVERNMENT are expected to produce a financial appropriation Bill in order to provide funds for CNRN who have exhausted their allocation. Prof. F. Ippolito, secretary-general of CNRN, has had talks with the Minister of Industry and a statement is expected shortly.

APPROVAL for the Bill for the ratification of the Italy-Euratom agreement concerning the research centre at Ispra becoming a Euratom centre has been given by the Senate Foreign Affairs Committee and the Bill will now be passed to the Assembly.

A FULL-POWER RUN has been completed by the 5 MW ISPRA 1 reactor. The heavy water cooled and moderated reactor was built for the CNRN by Allis-Chalmers and first achieved criticality in March, 1959.

A Belgium sub-critical reactor on show at the recent Nuclear Congress in Rome.

A LICENSING AGREEMENT has been reached by Gutehoffnungshutte Sterkrade of Oberhausen with General Atomics for the construction and sale of TRIGA and HGTR reactors in West Germany.

India

THE NRX TYPE REACTOR built at Trombay with Canadian help has now achieved criticality. The 40 MW reactor was built under the Colombo Plan.

Indonesia

TALKS HAVE BEEN CONCLUDED with the U.S.S.R. for co-operation in the peaceful uses of nuclear energy. Under the agreement the U.S.S.R. will give technical aid to Indonesia in the construction of a research reactor and a sub-critical assembly.

Israel

CRITICALITY was reached on July 6 by the 1 MW AMF pool type research reactor at the nuclear centre near Tel Aviv.

A PROJECT for a 70 MW pressurized water reactor by Fiat and Ansaldo Shipyards to propel a tanker is to be submitted to Euratom for study. CNRN have requested Euratom's participation in the study of the project.

Netherlands

INDUSTRIAL CONCERNS are reported to be collaborating with the national nuclear research centre in designing a 60 MW pressurized water reactor for marine propulsion.

Peru

A PLAN to build a 100 MW nuclear plant near Lake Titicaca is reported by the Peruvian Junta de Control de Energia Atomica. A U.S. power company is believed to be sponsoring the idea with a view to obtaining funds for the construction from the Export-Import Bank.

Philippines

THE FIRST nuclear components for the 1 MW research reactor at the Atomic Energy Commission's research centre have been completed by U.S. General Electric. The components include a 7,000-lb all-aluminium reactor thermal column case which forms a 13 ft tunnel between the reactor and the outside area which will be used for irradiation experiments.

South Africa

FINAL DECISION for a nuclear research reactor went in favour of the Allis-Chalmers high flux materials testing reactor. Dr. A. J. A. Roux, research director of the Atomic Energy Board, recently signed a letter of intent for about $3 million. The reactor will be an advanced version of the ORR reactor at present operating at Oak Ridge and will initially operate at 6.6 MW. Allis-Chalmers have built a similar reactor of 30 MW in Sweden (R2) and are completing a 20 MW at Petten, Holland.

Spain

SITES for three nuclear power stations are reported to be under consideration by the government. They are near Castrejon, about 50 miles from Madrid, for a 250 MW station, on the Guadalquivir marshes about 25 miles from Seville at La Horcada for a similar size plant and a third at an unspecified spot but believed to be in the Madrid area.

Sweden

FOURTH RESEARCH REACTOR in Sweden is now operating. R2-O, the 5 W pool type reactor built by Asea at an estimated cost of £103,000, is in the same pool as the R2 materials testing reactor at Studsvik and will be used mainly for irradiation protection tests and for preparing experiments with R2. R2-O is the first reactor to be built in Sweden on a completely commercial basis.

Switzerland

A NEW CONCERN, General Atomic Europe, has been formed by General Dynamics. With headquarters in Zurich, the company will initially have branches in Dusseldorf and Milan.

Turkey

A LETTER of commitment has been received by the Government from the U.S. AEC for a contribution of $350,000 towards the cost of a research reactor for the Nuclear Research and Training Centre under construction near Istanbul. The reactor is a 1 MW AMF swimming-pool type.

U.S.S.R.

ACCORDING TO A REPORT in *Soviet Weekly* work has started on a 2 MW reactor for the Academy of Sciences at Salaspils, near Riga. No details are given.

AN EXCHANGE of scientists agreement has been signed by the research centre at Dubna with CERN. Three scientists from each organization will change places.

A WORKING MODEL of an annular synchrocyclotron has begun operating in the high-energies laboratories of the Joint Nuclear Research Institute in Dubna, Moscow.

U.S.A.

PROPOSALS have been invited by the AEC for a nuclear power plant for McMurdo Sound in Antarctica. The invitation calls for the design of a 1.5 MW boiling water type reactor to be assembled in packages at a factory and shipped to the site for erection. The reactor should be in operation by 1962.

AFTER CONSULTATION between the Department of Justice and the AEC it has been decided that steps will be taken to test the decision made on June 10, 1960, by the U.S. Court of Appeals for the District of Columbia Circuit setting aside the AEC's issuance of a provisional construction permit to the Power Reactor Development Company for the construction of the Enrico Fermi nuclear power plant at Lagoona Beach in Michigan.

PERMITS ISSUED by the AEC for reactor construction are: Cornell University for a TRIGA reactor; North American Aviation for a 10-watt solution type reactor; The University of Maryland for a 10-kW pool-type reactor; General Dynamics for a 1.5 MW TRIGA-type reactor.

THE DISCONTINUANCE of the Standard Reactor Irradiated Units programme at Oak Ridge has been announced by the AEC. Under the programme radioisotopes were produced by the irradiation of suitable target material in a reactor, or by extraction of fission products from spent reactor fuel elements. Increasing availability of regularly processed isotopes has resulted in a decline of these types, however.

A POWER PEAK of 2,300 MW has been reached by KEWB, a 5-kW homogeneous reactor fuelled with a solution of uranium 235, after the installation of a new core. The reactor is operated by Atomics International at Canoga Park.

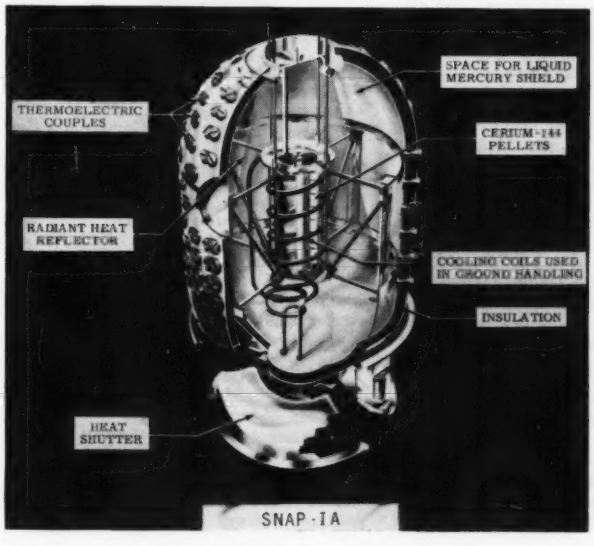
TRITIUM FOR TIMEPIECES incorporated in luminous paints is to be authorized by the U.S. AEC. Regulations will be amended to apply to home manufactured and imported watches and clocks. Activity is limited to 25 mc per instrument and for replacements, 15 mc per dial and 5 mc per hand.

Enriched uranium fuel being added to the L-77 laboratory reactor at Atomics International's new De Soto plant. The reactor was dismantled after operating on the old site at Vanowen and reassembled at the new laboratory.

PLANS TO ISSUE a permit to Lockheed Aircraft's Georgia Division to produce a low power reactor for exhibition in Latin America have been announced by the AEC. The reactor will be part of an exhibition to tour Brazil, Peru, Venezuela and other Latin American countries.

A NEW REPORT entitled, Business Statistics on the Atomic Industry, 1954-58, states that the U.S. industry have sold about $1.5 billion worth of nuclear reactors, components, materials and services during the five-year period.

ADDITIONAL FACILITIES are to be built by the AEC at the University of Tennessee's Agriculture Research Laboratory. Fred. E. Hicks Construction have been awarded the $249,610 contract.



A drawing showing the inner components of SNAP I-A, a 125w reactor system for auxiliary Power at The Martin Company's nuclear headquarters in Baltimore.

RESULTS of the study of the radiation accident at Oak Ridge have been announced by the AEC. Of the eight people exposed to the release of radioactivity seven received less than two rems to both lungs and bone.

DRESDEN has now operated at full power. The 180-MW boiling water plant, built at a cost of $45 million, first produced power on April 16, 1960.

THE CONTRACT for a Radioisotope Development Laboratory at Oak Ridge has been awarded to Kaminer Construction. The laboratory will cost $992,000.

THE RESULTS of the fourth quarterly survey of costs for civilian nuclear reactor projects currently under active design or construction in the U.S. have been published. The survey showed that costs of over $51 million were incurred during the three months ended March 31, 1960. Total costs for the 12-month period from June 30, 1959, to March 31, 1960, were $202.3 million.

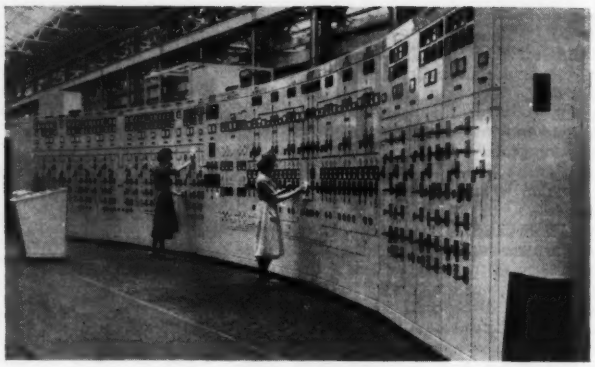
AN AGREEMENT has been signed by the AEC with the Tennessee Valley Authority to operate the Oak Ridge EGCR. Estimated cost of the reactor is $30 million. The agreement provides for the purchase of stand-by power by the AEC for use when the reactor is not producing power.

A SUB-CONTRACT has been awarded for the EGCR reactor vessel. Baldwin-Lima-struction at Oak Ridge. Baldwin-Lima-Hamilton of Philadelphia will do the pressure vessel work. Main contractor for the project is H. K. Ferguson.

THE MILITARY CONTRACT for a 2-3 MW compact reactor has been awarded to Nuclear Development with General Motors as sub-contractor for the power conversion unit. The contract is worth about $3-4 million.

A FUEL TEST LOOP is to be designed, built and operated by General Electric at Vallecitos for General Dynamics as part of their HTGC programme. The helium coolant will be circulated at 1400°F and 350 p.s.i.

Industrial Notes



The main control board for Hinkley Point receiving final attention at English Electric's Stafford works before despatch. The 33 panel board is 52 ft long.

Auxiliary burst slug detection equipment, designed and produced by **Plessey Nucleonics,** will be incorporated in the advanced gas-cooled reactor at Windscale. The installation comprises a specially designed precipitator and associated counting, recording and electronic equipment, and will be incorporated in the loop facilities. Portable and installed detectors for test loops and refuelling machines are also being developed by Plesseys, who have already supplied the main burst slug detection equipment.

An order worth £50,000 for two main reactor rod control boards for Trawsfynydd has been received by **Lancashire Dynamo Nevelin** from **Atomic Power Construction.** The 100-ft long boards will control the power supplies that lower and raise the graphite rods into the reactor.

W. H. Allen have announced that they have received an order from the **CEGB** for six Allen-Stoeckicht epicyclic gear units for motor-driven horizontal circulating-water pumps for Trawsfynydd. The units are designed to transmit 1,150 h.p. each continuously and reduce the motor speed of 960 r.p.m. to the pump speed of 180 r.p.m.

The **CEGB** have placed an order with **Ekco Electronics** for 86 radiation monitors for use at Berkeley, Bradwell and Hinkley Point. All are portable, battery-operated instruments.

A special products division for service to the nuclear industry has been established by **Equipment and Services.** The division is particularly concerned with timing or control devices and special-purpose control panels which are not included in the standard range of manufacturers.

The first **Construction Equipment Exhibition** will be held at Crystal Palace from June 15-24, 1961.

Examination of the 6-in.-thick concrete walls of the tower at the new Dungeness Lighthouse was carried out by **Pantak** using a cobalt-60 bomb with a strength of 7.5 curies. The source was contained in a holder especially designed by **Pantak,** and consists of a mild steel case with dished ends and filled with 500 lb of lead with an 80-lb hollow tungsten core.

The **AEA** has signed a contract for a **Stretch** class computer. The system will have random access disc storage units capable of transferring one word every 8 microseconds, six magnetic core storage units with retrieval time of 2.18 microseconds, and a vast magnetic tape backing store.

A film on Hinkley Point has been produced by **Technical and Scientific Films** in association with the **Film Producers Guild.** It was sponsored by the **English Electric, Babcock and Wilcox, Taylor Woodrow** consortia.

The **National Engineering Laboratory** report that experiments in the extrusion of magnesium alloy with cold-forming operations have been undertaken. Work is also being done on beryllium and bismuth.

Griffin and George recently held an exhibition of scientific instruments at Biakbeck College, London University.

The **Ministry of Power** have reconstituted the **Scientific Advisory Council** and have amended the terms of reference so as to emphasize that its advisory functions cover all aspects of research and development concerned with fuel and power from the laboratory to industrial application.

High Voltage Engineering have acquired all the stock of **Applied Radiation,** of Walnut Creek, Calif.

Semiconductors have acquired from **Sylvania-Thorn Colour Television Laboratories** the production equipment for the manufacture of n-p-n germanium power transistors and will soon be marketing these types.

A complete international catalogue of films on nuclear energy is being compiled by **Mr. A. N. Vorontzoff, 10 rue Mademoiselle, Paris 15,** and information on films already in existence would be appreciated.

A synopsis of the symposium on nuclear reactor containment buildings and pressure vessels held in Glasgow in May at the **Royal College of Science and Technology** has now been produced.

Cambridge Instruments have made an offer for the whole of the ordinary share capital of **Electronic Instruments.** The offer is on the basis of seven Cambridge 5s. shares for three £1 Electronic Instrument shares.

The **2nd International Compressed Air and Hydraulics Exhibition** will be held at Olympia from April 30 to May 4, 1962.

A contract to the value of £610,000 has been placed by the CEQB equally with **A.E.I.** and **British Insulated Callender's Cables** for the British half of the cross-channel submarine grid link.

A delegation from the **British Welding Industry** has recently visited the USSR at the invitation of the State Scientific and Technical Committee of the Council of the Ministers of the USSR.

The **First Electrical Fair** scheduled for Alexandra Palace for September 23 has been deferred until further notice.

Mullard have made a grant of £25,000 towards a new physics laboratory at Oxford University.

Cook and Nicholson have been appointed agents for North-East England by **Weldcraft** and will handle sales of gas welding equipment.

Wolf Electric Tools have purchased the Hanger Lane factory premises of **Arrow Electric Switches.**

Specialized consultative, design and engineering services in electronic instrumentation are now offered by **Bristol Aircraft.**

The **George Kent** mobile exhibition of instrumentation and automatic control equipment has recently visited Moscow.

Aveley Electric have been appointed the sole representatives for **Allen B. DuMont Laboratories** in the United Kingdom for scientific instruments and industrial tubes. Aveley will sell oscilloscopes, oscilloscope cameras, pulse generators, vacuum tube voltmeters and accessory equipment as well as industrial and special cathode-ray tubes, multiplier phototubes, storage tubes and microwave tubes.

Recent changes of address are:

Tracerlab (Holland) to 119 Singel, Amsterdam.

Precision Components to Cranborne Road, Potters Bar. Tel: Potters Bar 3444.

AEI Press office to Crown House, Aldwych, W.C.2. Tel: Temple Bar 8040.

Dewhurst and Partners publicity department to 1 York Street, Twickenham. Tel: Popesgrove 9953.

Yates Plant (Baker Perkins) to Hebburn-on-Tyne, Durham.

Processes and Equipment

For further information on any item please enter the relevant number on the Reader Service Card enclosed with this issue and forward the card to the address given.

Glove Box with Turntable

Advanced design features of the Secray Mk. III glove box include the provision of a rotating turntable inside the box, and the use of polyester glass fibre laminate in the construction, giving increased strength and lightness. Of circular form, with domed top, mounted on braked castors and with a 6-in height adjustment, the standard model has a single large window, with two 6-in glove ports giving access to the turntable. This is also moulded from glass fibre laminate, and can be manually rotated, being mounted on six peripheral castors and a central plate running on a sealed bearing with a thrust race. Service leads, such as gas, water, electricity, etc., are carried on this central plate, and the rotation of the turntable, which can be stopped in any position by a foot-brake, is limited to a single revolution, to avoid twisting these leads.

Exit ports (e.g., centrifuge and trash ports) with snap lids and O-ring seals are arranged in the floor of the box, underneath the turntable, which has a sector cut away for access. Entry is, in the standard model, by means of an 8-in. bag port to the right of the window; additional ports and windows can be provided, if required.

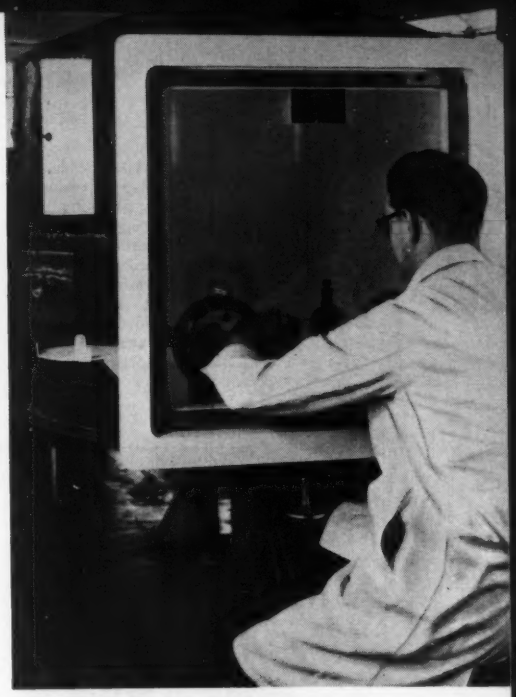
Designed to operate at a partial vacuum (4-in. w.g.) the box has a 6-in. explosion valve in the roof, which opens at an internal pressure of 1-in. w.g.; a bag ring is provided for connection to the laboratory extract system. Normally, the vacuum is maintained by an external ejector or vacuum pump; a standard Vokes extract filter is located inside the box by a quick-release clamp designed for one-hand operation.

Servicing of the thrust bearing can be carried out externally, without disturbing the seal. There is also a secondary seal which can be brought into use, should the main seal itself require attention. The turntable, also, can be lifted clear of the floor of the box for easy decontamination.

Two boxes of this type have been recently supplied to Dounreay.

(Seton Creaghe Engineering, Ltd., G.W. Trading Estate, Park Royal Road, London, N.W.10.)

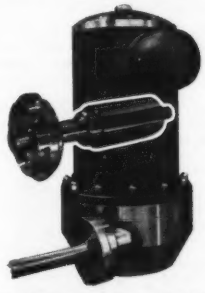
1333



The Secray Mk. III glove box.

Heavy Water Pump

An interesting feature of a Charmilles canned pump, recently supplied for the heavy water purification circuit of the Wurenlingen (Switzerland) DIORIT reactor, is that it was developed from a pump which has been built by the company for 25 years for central heating work. With a capacity of 10 gal/min against a pressure head of 164 ft, the pump is of stainless steel, with synthetic water-lubricated bearings and a simple hydrostatic thrust bearing.



Charmilles heavy water pump, showing external appearance and (inset) pump rotor.

The stringent requirements for heavy water circuits are well known, and the extensive tests required included tightness tests with helium.

(Charmilles Engineering Works, Ltd., 109 Rue de Lyon, Geneva.)

1335

New X-ray Tubes

X-ray fluorescence analysis will be improved, particularly for copper and nickel, by new Machlett Laboratories, Inc., tubes in which the characteristic radiation from impurities in the tube anode is considerably reduced. The tubes are available with 5 x 5 mm focus and tungsten or platinum anodes, and 6 x 6 mm focus, with tungsten, platinum or molybdenum anodes. All are fitted with beryllium windows, and operate up to 50 kV.

New Machlett Laboratories X-ray tube.

(Watson and Sons (Electro-Medical), Ltd., East Lane, North Wembley, Middlesex.)

1336

Integrated Crystal-Photo-Multiplier

Better resolution is claimed for a new development in connection with scintillation detectors using thallium-activated sodium iodide crystals. Instead of mounting the crystal in a windowed can, and placing it in contact with a conventional photomultiplier, the crystal is mounted directly on the face of a photomultiplier. A Hilger and Watts crystal, 3 in. diameter x 3 in. thick, is mounted on the face of an E.M.I. 9531A multiplier and the whole is hermetically sealed in a canister. Resolution with a Co-60 source is slightly better than 4 : 1, peak/valley ratio; the units are very suitable for gamma-ray spectrometry. Another type, with a 1 in. crystal, mounted on a Type 9524 photomultiplier, is being developed for detection probes.

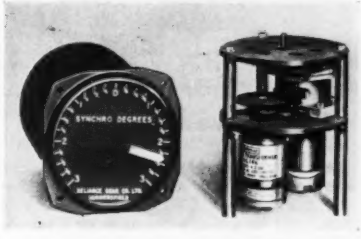
New Hilger and Watts scintillation detector.

(Hilger and Watts, Ltd., 98 St. Pancras Way, Camden Road, London, N.W.1.)

1337

Servo Gearboxes

Gear ratios up to 43 x 10^3 : 1 with minimum backlash are said to be possible with the spring-loaded split gears used in a range of servo gearboxes manufactured by the Reliance Gear Co., Ltd. Made in two sizes, standard and miniature, the boxes are of



Reliance miniature servo gearbox.

modular design, using standard 7-hole end plates for mounting rotating components, such as servo-motors, potentiometers, synchros., etc., and the shafts may be extended at either side in any position; ratios or components may be interchangeable for "bread-board" and prototype work. Torque-limit clutches and eddy current dampers may also be provided. Diameters of the two sizes are 3 in. and 8¼.

(Reliance Gear Co., Ltd., St. Helens Gate, Almondbury, Huddersfield.)

1338

Vibration Monitor

Measurement, monitoring, and recording of vibration in machines and structures is carried out by a new Dawe device which compares a signal derived from a vibration pick-up with a pre-set bias voltage, operating alarms or shutting down machinery when vibration exceeds a predetermined limit. The pick-up is of a robust moving coil design,

The Dawe vibration monitor.

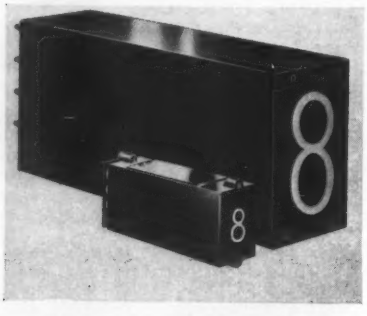
hermetically sealed, and with screened leads up to 200 ft long, giving an output voltage proportional to the velocity of vibration from 20 to 400 c/s. The meter is calibrated in peak values of displacement for a simple harmonic motion applied to the pick-up, and the alarm level can be set between 20 and 100% of full-scale reading on any of the four ranges, which cover from 0.001 in. to 0.030 in.

(Dawe Instruments, Ltd., 99 Uxbridge Road, London, W.5.)

1339

Digital Display Unit

A new design of digital display unit, manufactured by Counting Instruments, Ltd., is approximately four times the size of previous models, and can display a single



The new Counting Instruments' display unit.

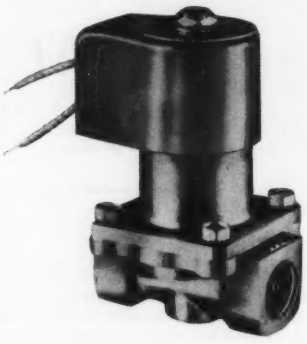
character 3¼ in. high × 2 in. wide, thus enabling it to be read from considerable distances. The display, projected from the rear, may be a single character or a number of smaller characters or words, with uniform intensity of illumination.

(Counting Instruments, Ltd., 5 Elstree Way, Boreham Wood, Herts.)

1340

Solenoid Valves

Under licence from the Automatic Switch Co., of New Jersey, Dewrance-Atco packless solenoid-operated valves are being manufactured in Britain. The range is



A typical Dewrance-Atco solenoid valve.

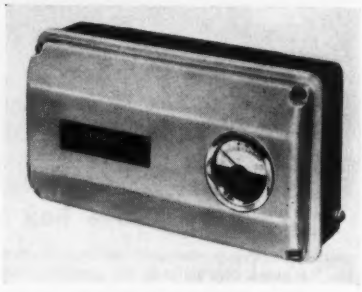
extensive, varying from ⅛-in. pipe to pilot-operated units with 6-in. ports, in materials ranging between bronze, cast steel, stainless steel and nylon, while operating pressures range from full vacuum to more than 5,000 p.s.i., and temperatures from −320°F to 600°F. Two-, three- and four-way valves are included in the range.

(Dewrance and Co., Ltd., Great Dover Street, London, S.E.1.)

1341

Level Indicator

A new capacitance-operated electronic level indicator, the Levolog, is now available for the continuous remote measurement of almost any type of material in tanks, silos, hoppers, etc. The control unit, which has a built-in calibrating instrument, is provided



The Levolog control unit.

with a robust dustproof and weatherproof enclosure; the main indicator is supplied to suit particular requirements. The electrode system, which can be of the flexible type for vessels over 6 ft. deep, may be up to 60 ft. long, dependent upon the material to be measured. Calibration may be in gallons, tons, or other appropriate units, and near-linear scaling is possible by suitable design of the electrode system.

(Thomas Industrial Automation, Ltd., Station Buildings, Altrincham, Cheshire.)

1342

BRIEFLY . . .

Devcon "plastic lead," a combination of 94% lead and 6% plastics material, is announced by **E. P. Barrus (Concessionaires), Ltd.,** of 12 Brunel Road, Acton, London, W.3. Within three hours of the addition of a curing agent, Devcon L changes from a putty-like substance to the consistency of metallic lead, with good adhesive properties to most metals, porcelain, concrete and wood. **B145**

Suba Hydraulics, Ltd., 86 Lind Road, Sutton, Surrey, announce the development of a new blending machine which will deliver measured quantities of various types of liquids, just prior to delivery, and avoid the settling which sometimes occurs with pre-mixed blends. Hydraulic or pneumatic operation can be arranged, and the units designed for inflammable or corrosive liquids, if required. **B146**

"Amberlite 200" is the first of a new series of ion-exchange resins said to have exceptional stability, developed by Rohm and Haas (Philadelphia), whose British subsidiary is **Charles Lennig and Company (Great Britain), Ltd.,** of 26 Bedford Row, London, W.C.1. It is recommended where solutions are "difficult," or operating temperatures are high. **B147**

The Schori division of **F. W. Berk and Co., Ltd.,** Brent Crescent, North Circular Road, London, N.W.10, announce "Berkalloy," a new zinc-aluminium flame-spray material. Tests over eight years have shown that this alloy possesses the advantages of zinc in alkaline conditions, and those of aluminium in acidic atmospheres. **B148**

New drawing office materials by the **Ozalid Co., Ltd.,** Langston Road, Loughton, Essex, include "Fastline" intensifying paper and cloth which will not only produce a sub-master drawing from a pencil drawing, but will produce it at the same speed as a paper print, thus removing a major handicap of earlier materials. **B149**

Imperial Chemical Industries Limited, Thames House, Millbank, London, S.W.1, have introduced a range of "Silcoset" rubbers which, in the form of solvent-free pastes, can be cured by addition of a catalyst, without heat. After curing, they exhibit the properties of normal silicone rubbers and are suitable for sealing, patching, caulking or potting applications. **B150**

A flexible coupling, the "Quadriflex," introduced by **R. and J. Dick Limited,** Greenhead Works, Glasgow, S.E., has a number of good points, including the absence of bolts or any form of protrusion; consisting simply of two flanges and a two-piece moulded rubber insert, or sleeve. A combination of angular misalignment, parallel misalignment, end float and torsional load can be accepted without trouble. **B151**

The PP5 stabilized power supply unit for laboratory work, developed by **Advance Components Ltd.,** Roebuck Road, Hainault, Essex, gives a continuously variable supply from 0-15V at a maximum current of 500mA, with a maximum ripple of 1 mV. The transistorized circuit includes automatic overload protection adjustable from 50-500mA. **B152**

The A1654 Wadsworth controlled-cathode electrolyser is one of the new products introduced by **Southern Instruments Ltd.,** Frimley Road, Camberley, Surrey. Gravimetric electrolytic analysis has been handicapped by the need to control the potential manually, the new unit prevents the potential from rising beyond the preset value, and different metals may be plated out in turn. The maximum output is 10A. **B153**

The Chemical and Insulating Co., Ltd., Darlington, Co. Durham, announce quantity production of "Supermag," an improved magnesium carbonate-asbestos insulating material, in preformed sections and slabs. Strength, ease of handling, and moulding accuracy are said to be considerably better than previous types of magnesia compounds. **B154**

New worm gear jacks, covering the range 2-100 tons in eight standard models, which are also suitable for linear actuators, either singly or ganged, are announced by the **Consolidated Pneumatic Tool Co., Ltd.,** 232 Dawes Road, London, S.W.6. **B155**

Pantak, Ltd., Vale Road, Windsor, Berks, are marketing the Siemens 15 MeV mobile betatron enabling radiographs of steel 16 in. thick, to be taken with 1-2 h exposure. Weight is about 3½ tons; consumption is approximately 12 kVA. A magnification technique, giving an image up to 3X the flaw size, can be used. **B156**

Temperature Monitoring

Continuous scanning of up to 12 thermocouples or resistance bulbs is provided by a new West instrument, which utilizes mercury switches, operated by motor-driven cams, for changing from one measuring head to another, thus reducing the liability of error from poor mechanical contact or corrosion.

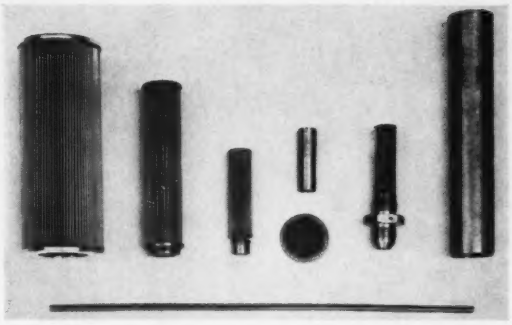
The instrument, which has a 5-in. scale edgewise millivoltmeter, can be fitted with either one adjustable "high" contact, for alarm and shutdown, or two independently adjustable contacts so that independent action is taken at a lower setting.

(West Instrument Ltd., 52 Regent Street, Brighton, Sussex.)

1343

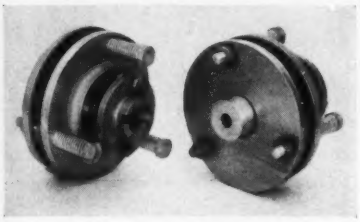
Right: Typical Poroloy filter units.

Below: West 12-way temperature monitor.



Overload Clutches

Originally designed for Foster motor-driven voltage regulating transformers, the Metastream friction clutch is now being marketed for use with any type of service where torque or distance limits are required,



Metastream friction clutch.

being more controllable and convenient than shear pins and more economical—particularly in low-speed applications—than centrifugal clutches. A flexible coupling is incorporated.

This, the first of a projected range, is 3½ in. overall diameter, and 2⅜ in. long. The slipping torque may be adjusted by three bolts, to a maximum of approximately 5 lb-ft.

(Metaducts, Ltd., Catharine Wheel Road, Brentford, Middlesex.)

1344

Temperature Trip Amplifier

The AT 840 temperature trip amplifier, developed to U.K. AEA requirements, has been designed for stability and reliability, as well as sensitivity. Operating by comparison between the thermocouple output and a reference voltage, the resultant being fed to a two-stage magnetic amplifier, the unit can,

The AT 840 temperature trip amplifier.

by variation of the reference voltage, be set to trip at any temperature from 0-1,000°C, to a setting accuracy better than ±1°C, and a long-term stability of better than ±2°C. Continuous indication of margin-to-trip is given by a built-in indicator; an external recorder can be connected if desired. Three relays are provided; one is de-energized at the trip temperature and one at an adjustable low margin before the trip temperature. The third operates at a fixed high margin below trip temperature.

A unit of similar design has been developed on behalf of A.E.I. for the Berkeley station.

(Ultra Electronics Limited, Western Avenue, London, W.3.)

1345

High-performance Filters

Poroloy is the latest addition to the extensive range of filter media manufactured by the Vokes Group. Of fine woven wire, sintered after weaving, Poroloy is made in two types, CM and T according to the type of weave, and is generally made of 18/8 stainless steel, although it can also be obtained in nickel-chrome, Inconel or, in fact, almost any material capable of being drawn into fine wire. The sintered construction, by securely bonding all wires at the point of contact, gives freedom from media migration, and exceptional fatigue strength, so that it can be used under pressure-surge and heavy vibration conditions.

Good ductility and ease of welding, silver-soldering, or cementing are other convenient properties, and filter inserts can be manufactured in the form of sheets, tubes, pleated discs or cylinders, etc., and can be designed to withstand differential pressures of 3,500 p.s.i. Operating temperatures range from −350°F to 500°F, or higher, according to materials. Nominal pore sizes range from 2-1000 μ.

(Vokes, Ltd., Henley Park, Guildford, Surrey.)

1346

CATALOGUES

New publications to hand from **Isopad, Ltd.,** Barnet By-pass, Boreham Wood, Herts, cover electric heating mantles for laboratory and glass apparatus up to 2,000 l, and industrial surface heaters for vessels up to 3,000 gal; pipe lines, valves, etc.; and the first issue of the **Isopad Development News.**

"Cooper Electroheat," a handbook of stress relieving, has been issued by **Cooper Electroheat Limited,** 164 Lord Street, Southport, Lancs.

Standard Telephones and Cables, Ltd., have issued three new publications; "Some Temperature Compensation Problems associated with Transistor Circuits"; "Binary Counting Circuits using Alloy Junction Transistors"; "Hermetic Seals."

Pollard Bearings, Ltd., Ferrybridge, Knottingley, Yorks, have issued a new catalogue on "Self-Lube" bearing pillow blocks and bearing units.

A catalogue of electronic apparatus and services such as calibration and reconditioning has been received from **Universal Electronics, Ltd.,** 22 Lisle Street, Leicester Square, London, W.C.2.

An abridged (eight page) catalogue giving brief details of the entire range of precision electronic instruments including a number of new lines has been received from **Muirhead and Co., Ltd.,** Beckenham, Kent. Other publications include details of precision r.m.s. decade voltmeters and automatic recording wave analysers.

Miniature "Cirscale" moving-iron and moving-coil, and moving-coil "Edgewise" instruments are described in three new publications received from the **Record Electrical Co., Ltd.,** Broadheath, Altrincham, Cheshire.

Manufacturing facilities available for the fabrication of instrument panels of all types are listed in a leaflet received from **Millett, Levens (Engravers), Ltd.,** Stirling Corner, Barnet By-pass, Boreham Wood, Herts.

New publications from **George Kent, Ltd.,** Luton, Bedford, describe orifice fittings for flow-meter work and a new small design of water meter.

Ardente Acoustic Laboratories, Ltd., 8-12 Minerva Road, North Acton, London, N.W.10, have issued a new catalogue illustrating their range of miniature electronic components.

A 110-page handbook "Molybdenum Metal" giving full and up-to-date information on all forms of molybdenum has been received from the **Climax Molybdenum Company of Europe, Ltd.** 2 Cavendish Place, London, W.1.

A booklet "DCMC Industrial Aerosols" giving details of the complete range of aerosol-packed industrial products including colour coding paints, silicone mould release, rust inhibitor, degreasing fluid, etc., has been received from the **Dudley Court Machine Co., Ltd.,** 2A Parkhurst Road, London, N.7.

Negretti and Zambra, Ltd., 122 Regent Street, London, W.1, have issued a leaflet on their new "Mersteel" rigid-stem dial thermometers, with 4½-in. dial, and 8-in. or 11-in. stem, for general-purpose work. They are available in 11 colours, in accordance with B.S. colour coding. Guaranteed accuracy is ½% full scale.

The range of Degussa pyrometers, thermocouples, and resistance thermometers is briefly listed in a leaflet received from **Bush Beach and Segner Bayley, Ltd.,** St. James' House, Brazennose Street, Manchester, 2.

"Industrial Pipework" is the title of a handbook issued by the Pipework Engineering Division of **Stewarts and Lloyds, Limited,** Broad Street Chambers, Birmingham, 1, containing a great deal of useful information on the manufacturing facilities and services available. In addition, there is a section on pipework design, with calculations of bores and thicknesses, tables, and charts of pressure drops for water and steam, etc.

Electrothermal Engineering, Ltd., 270 Neville Road, London, E.7, have issued a well-illustrated catalogue of electronic components, including resistors, capacitors, valve retainers and wiring jigs.

The Sonoray ultrasonic flaw detector Model 5, claimed to be the smallest and lightest on the market for its performance, is described in a leaflet received from **Branson Instruments Inc.,** 40 Brown House Road, Stamford, Connecticut, U.S.A.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 825,459. Liquid metal pumps. L. R. Blake. To: British Thomson-Houston Co., Ltd.

An arrangement is described in which both flux and current are generated by the same winding instead of using two windings as in B.P. 794,048, one producing the flux and the other winding the current flow.

B.P. 825,662. Nuclear reactors. G. Camac. To: A.E.I.-John Thompson Nuclear Energy Co., Ltd.

Refers to reactors having a coolant of carbon dioxide gas and in particular to an arrangement for isolating fuel channels. The isolating valves in the upper ends of individual fuel channels are actuated by servo apparatus operated by liquid carbon dioxide discharged into the coolant system of the reactor. (If nitrogen or helium is employed as coolant, liquid nitrogen or helium is used.) In order to maintain the gas liquefied, high pressure is required (1,500 p.s.i.) and the pressure drop on the exhaust side would cause solidification. By discharging into the coolant system, the pressure drop is considerably reduced (by the back pressure in the system) and freezing is avoided.

B.P. 826,513. Glandless shaft drive transmission systems. G. O. Jackson. To: U.K. Atomic Energy Authority.

A rotary movement is transmitted through a seal from an exterior to an interior shaft by a crank at the end of the exterior shaft carrying an externally toothed pinion meshing with a large internally toothed gear wheel on the interior shaft. The pinion does not rotate relatively to the casing so that a flexible sealing means between pinion and casing in the form of a bellows can follow the movement of the crank-carried pinion and prevent any leakage of gas from a vessel, or of air into the vessel.

B.P. 826,529. Neutronic reaction fuel. To: General Electric Co. (U.S.A.). (Add to: 796.989.)

An alloy containing 5 to 23 wt% U^{233} or a mixture of U^{233} and U^{235} and from 0.001 0.20 wt% B^{10}, the balance being U^{238}, B^{11}, and either aluminium or zirconium, with the boron evenly distributed throughout the alloy.

B.P. 826,938. Production of grinding surfaces. A. Blainley. To: U.K. Atomic Energy Authority.

This refers to grinding with relatively hard surfaces (stainless steel; nickel alloys) which are first cleaned by abrasion and washed. A layer of a suspension of particles of zirconium or titanium of a size range of 20 up to 200 μ in an organic liquid (e.g., xylene) is then applied, the body heated to evaporate the liquid and then heated further in vacuo to at least 900°C to cause the formation of a diffusion coating on the body which is allowed to cool in vacuo. Uranium carbide and uranium oxide may be ground with such treated surfaces under molten metal of low melting point (sodium-potassium alloy, lithium, lead, bismuth, tin or alloys of such metals).

B.P. 827,015. Shaft seals. T. Barett, D. English, K. J. Williams. To: U.K. Atomic Energy Authority.

A seal against gas under pressure is effected by oil under pressure by two series of oppositely inclined viscosity grooves separated by a continuous ungrooved surface. The series of grooves on the gas pressure side is so arranged as to generate a greater liquid pressure than the other series so that a gas liquid interface is set up in the former series.

B.P. 827,060/061/062. Heat exchange apparatus. S. G. Bauer, N. Battle. To: Rolls-Royce, Ltd.

The spaces between the main portions of the tubes are occupied by strips bent to zig-zag form so as to divide these spaces into a number of parallel passages. Packs of tubes provide a multi-pass flow path for the liquid (liquid sodium), the design avoiding large pressure losses in the gas flow (air).

B.P. 827,063. Heat exchange apparatus. S. G. Bauer, N. Battle. To: Rolls-Royce, Ltd.

A plate-type heat exchanger with symmetrically disposed domed projections and dimple-like depressions coinciding with the domed projections on the other surface of the plate arranged in a pattern (regular hexagon). Between the stacked plates true counter-current flow is obtained with low pressure drop between inlet and outlet.

B.P. 827,085. Nuclear reactors. To: U.S. Atomic Energy Commission (U.S.A.).

It has been found that the power level of a boiling reactor may be correlated to the demands of a load by providing means to regulate the temperature of the feedwater entering the fuel elements. This temperature is inversely related to the power demand.

B.P. 827,321. Sealing devices. J. C. Guild. To: U.K. Atomic Energy Authority.

A liquid dip seal between two relatively rotatable parts characterized in having in its dipping part a passageway from a lower level on one side to a higher level on the other side. Two seals arranged in "opposition" provide protection against pressure surges in either a "forward" or "reverse" direction through the seal.

B.P. 827,784. Electric pumps. D. M. Harris, E. Holland. To: U.K. Atomic Energy Authority.

A glandless electric pump for pumping an electrically insulating liquid with a wet-winding electric motor having stator windings insulated by ceramics (ceramic beads) or flexible fibre-glass or silica tubing which in fact merely act as spacers while insulation is maintained by the liquid pumped.

B.P. 827,977. High energy radiation detector. To: General Electric Co. (U.S.A.).

A semi-conductor P-type layer of selenium on a conductive base (aluminium) and above it a semi-conductor N-type phosphor layer of silver activated cadmium sulphide or selenide forming a broad area P-N junction. The free surfaces have low resistance contact with electrodes, the one on the phosphor layer of such thickness as to be opaque to visible light but transparent to X-rays and gamma rays. Incident high energy radiation varies current flow through an instrument circuit. The instrument is self-contained and compact.

B.P. 828,054. Vessel charging and discharging apparatus. J. Britt. To: Rolls-Royce, Ltd.

Refers to an assembly of axially spaced plug-like seal members of soft metal to prevent leakage from a liquid metal-cooled reactor when fuel elements are exchanged. The corresponding faces of the reactor vessel are formed of hard metal. When passing the assembly holding the fuel elements through the seals the plug-like members are successively deformed by the co-operating surfaces on the vessel so that the sealing surfaces at the charging aperture are greater than those of the discharging aperture. A discharging cylinder may be used into which the assembly may be introduced and there may be also a charging cylinder in which further successive deformation of the sealing surfaces is effected.

B.P. 828,055. Nuclear reactor units. J. Britt. To: Rolls-Royce, Ltd.

A core having a number of fuel channels, the axes of which intersect at a point outside the core, on the fuel-handling side (preferably below the core). The fuel-handling member is formed by a pair of telescoping parts one of which receives the fuel rod, the other being mounted for universal movement about the intersection of the axes.

B.P. 828,352. Nuclear reactor control. S. Untermeyer, E. Hunter. To: U.S. Atomic Energy Commission.

At least part of the control members are connected to one another to form a group unit with a number of absorber members extending into the active portion of the reactor. Some of the members can be moved longitudinally relative to each other to vary the neutron flux whereby the movement of any member changes the shadowing effect of this member upon the other members of the group. Alternate sections of the members may have different neutron absorbing characteristics.

B.P. 828,468. Reactor pressure vessel. P. H. W. Wolff, H. S. Arms. To: English Electric Co.

A shallow heat barrier is formed of "sandwiches" of corrugated metal sheets containing stagnant gas, arranged inside the vessel from the top and extending down to a level below the upper surface of the moderator. These sandwiches may be manufactured flat, but flexible enough to be mounted along the curvature of the vessel.

B.P. 829,139. Nuclear reactor fuel elements. L. M. Wyatt, R. P. Kinsey. To: U.K. Atomic Energy Authority.

A protective sheath must be strong enough to withstand the pressure of gaseous fission products but should have minimum mass thus reducing neutron absorption. Besides such sheaths are possibly made of expensive materials (zirconium; beryllium). The difficulty is overcome by inserting a sealed tubular container of zirconium in the fuel, so that gaseous fission products, causing swelling of the fuel, will compress the tube in preference to bursting the sheath.